APPLICATION OF RECONSTRUCTION TOMOGRAPHY IN TWO-PHASE FLOW STUDIES

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CERTIFICATE

This is to certify that this work on "Application of Reconstruction Tomography in Two-phase Flow Studies" by Mr.M.D.SESHADRI has been carried out under our supervision and has not been submitted elsewhere for the award of a degree.

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ABSTRACT

The technique of reconstruction tomography used in radiology is applied to measure density in bubbly air-water flows. The 'Convolution' algorithm used, converts the fan beam data to a parallel beam data and then a suitable filter is used.(in our case the generalise filter). Then convolution is carried out, followed by superimposition. Printing of density values is done in the format of density maps. The Generalised filter used proved superior to the Shepp and Logan filter which was used as a reference.

The error band in the measured values of density is -0.03 and its underestimation is fairly constant and predictable within the range of ρ 0.6 to 1.0 .

The New Algorithm is an alternate method of reconstructing densities but the C.P.U time is more. The error was practically zero, for a certain class of density distribution called radially symmetric distribution.

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CHAPTER 1

INTRODUCTION

One of the major problems confronting a Nuclear reactor safety engineer, , is the measurement of void fraction or density during Loss-Of-Coolant-Accident (LOCA). The development of an accurate and reliable two-phase flow measurement technique for various flow systems and components in light water reactors is of great importance and significance. The present study looks at such a new vista, which will alleviate the problems in the chemical industry, food processing, waste treatment and fludized flow systems, including fludized bed combustors. The method used is that of computerised axial tomography.

The most familiar images are those formed directly by optical instruments using visible light reflected or transmitted by an object. However, in many applications in which an image is required, we can make only indirect measurements by probing the object with invisible radiation or by interpreting it. Often the measured data is not in a

form suitable for immediate interpretation, but is related to the image in a known way. The general aim of all image reconstruction procedures or algorithms is to process the data to form an image and so to facilitate the interpretation of measurements.

To determine the density of the object under test various strip integrals corresponding to a particular angle of view were taken and the set of strip integrals are called projection of the object. Given a number of such projections at different angles of view, the estimation of the corresponding distribution within the object is the basic problem of image reconstruction from projections. Computerized Axial Tomography (CAT) is the most significant application to date of image reconstruction from projections.

According to Webster, 'TOMOS' means cutting and graphy is study and together mean a special X-ray/Gamma ray technique by which detailed images of a structure lying in a specific layer of tissue may be obtained, with images of structures in other layers eliminated or blurred.

A basic and crude form of CT (computerized tomography) was practised in Japan as early as 1947 and called as Rotatography by taking several X-ray images at different angles (0-360°) around the patients body.

The practice now days is to use a detector to collect the data and process using a computer, which has the capability to detect minute differences in X-ray/Gamma ray attenuation coefficients, instead of directly using X-ray pictures (Radiograms) as was done with Rotatography.

The present study involves "Convolution" algorithm. This algorithm is considered as highly efficient by numerous investigators in computerised axial tomography. The reconstruction method in use in all CTs is the Convolution method.

The above method has been aptly been demonstrated by Kulacki et al (1). Reconstruction tomography was adapted to the needs of two-phase flow density measurements. Design of a prototype scanning densitometer has also been suggested by Schlosser et al (2).

There are several parameters in the Convolution algorithms and becomes implementation dependent. The present study considered all the free parameters and their effect on the problem in question. The parameters considered are viz:-

1. Number of scans - N -
2. Number of beams in a scan - M - and
3. Various filter functions

The reconstruction algorithm used is that of Kwoh et al (3) with the Shepp and Logan filter. The present study investigates other possible filters like Ramachandran filter, Parabolic filter and Generalised filter.

The present study has been undertaken with the main objective to improve the reconstruction algorithm used in the work of Kulacki et al (1). Especially the filter function (Shepp and Logan) used has been carefully investigated.

A FORTRAN program for the algorithm has been written and implemented with flexibility to change number of Rays per view and number of projections in scan as per the computer time and accuracy needed.

Specific objectives of the study are:-

1. To find the optimum values for number of Rays per projection (LITM).

2. To find the optimum values for number of projections in scan (N) and

3. To find the best filter.

LITM was checked for two values 20 and 40 .

N was checked for three values 10, 20 and 40.

Parabolic filter, Ramachandran filter and four cases of Generalized filter were investigated, graphs plotted. In this test for best possible filter Calibration curves were drawn for a few known densities of material like Air, Water, Walnut and Pine.

The data used in all the computations have been taken from Kulacki et, al (1).

A 'New Algorithm' was investigated to get exact reconstruction. This was developed by Prof.R.K.S.Rathore. The data used were test values. Experimental Data is to be adopted for this method.

CHAPTER-2

LITERATURE REVIEW

2.1 OVER VIEW

One of the complex situations to analyse in Nuclear reactor safety is the two-phase flow condition and void fractions formed in them. There are various methods used for this purpose and Kulacki et al (1) have amply and sufficiently proved in their study the use of scanning gamma-ray densitometer. There are no disturbance caused which are inevitable if probes are inserted in the flow for point density measurements. Also a scanning gamma-ray densitometer offers the potential for obtaining both point and cross-section averaged values of density without disturbing the flow field (because of invasive technique). Most of the present study is based on the technique involved and developed by (1).

The other prominent in the category of invasive type of measurement of void fraction are:-

Nuclear Magnetic Resonance (NMR) and

Ulltrasonics;

Computerised axial tomography (CAT) the method adapted to two-phase flow in Nuclear reactors by Schlosser et al (2) with the aid of Kwoh et al (3) algorithm is explained in the following pages.

Ramachandran et al (5) has explained in their study a simplification of reconstruction by using convolution instead of Fourier transform, which greatly reduces the computer time and space needed alongst with a better accuracy.

2.2 RAMACHANDRAN FILTER

This new technique is used for 3D reconstruction from their transmitted radiographs. Convolution is used in the real space of the object, without using Fourier Transforms (F.T's). The object is rotated about an axis at right angles to the direction of a parallel beam of radiation, and sections of it normal to the axis are reconstructed from Data obtained by scanning the corresponding linear strips in the shadowgraphs at different angular settings.

Since convolution method involves only one summation over one variable at a time, while F.T requires two, convolution is much faster. It is also shown by tests that convolution method is more accurate.

The basic step in the solution of reconstruction problem consists of replacing the three dimensional density distribution by a set of two-dimensional density functions in a series of sections perpendicular to . Z-axis.

$$F(R;\theta) = \int_{-\infty}^{\infty} g(l;\theta)\exp(2\pi iRl)\,dl \quad \ldots\ldots\ldots(1)$$

$$f(r;\phi) = \int_{0}^{2\pi}\int_{0}^{+\infty} F(R,\theta)\exp(-2\pi iRr\cos(\phi-\theta))R\,dR\,d\theta \quad \ldots.(2)$$

Suppose we define:

$$g'(l,\theta) = \int_{-\infty}^{\infty} |R|\; F(R;\theta)\exp(-2\pi iRl)dR \quad \ldots\ldots(3)$$

Equation (2) for $f(r,\phi)$ becomes

$$f(r,\phi) = \int_{0}^{\pi} g(r\cos(\phi-\theta),\theta)\,d\theta \quad \ldots..(4)$$

Fourier inverting (1)

$$g(l;\theta) = \int_{-\infty}^{\infty} F(R;\theta)\exp(-2\pi\; iRl)dR \quad \ldots..(5)$$

F.T of $g(l;\theta)$ = (F.T. of $g(l;\theta)$) x (F.T. of $q(l)$)

R is the F.T. of the function q (l).

$$|R| = \int_{-\infty}^{\infty} q(l)\exp(2\pi iRl)\,dl \quad \ldots..(6)$$

Using convolution theorem for the inverse of the product of F.T's

$$g'(l;\theta) = \int_{-\infty}^{\infty} g(l_1;\theta)\, q(l-l_1)\, dl_1 \qquad ......(7)$$

$$q\ (l) = -\int_{-\infty}^{\infty} /R/ \exp(-2\pi\, iRl)\, dR \qquad ......(8)$$

The integral diverges for the limits so replacing the limits by -A/2 and +A/2 where A= 1/a.

$$q_A(l) = \int_{-A/2}^{A/2} /R/\ \exp\ (-2\pi\ iRl)\ dR \qquad ......(9)$$

$$\begin{aligned} q(na) &= 1/4a^2 && \text{for } n=0 \\ &= -1/\pi^2 n^2 a^2 && \text{for } n \text{ odd} \qquad ......(10) \\ &= 0 && \text{for } n \text{ even} \end{aligned}$$

$f(r,\phi)$ is the two dimensional density distribution.

$f(r,\phi,z)$ will be the data of three dimensional density distribution using all linear strips at Z in the different shadowgraphs taking at various angles θ .

$F(R;\theta)$ is the Fourier transform of $g(l;\theta)$ where $g(l;\theta;z)$ is the logarithm of the ratio of intensity at point P(z,l) to the incident intensity.(which is a measure of the linear integral).

The biggest problem in this filter is that it is zero for all even values so the filter becomes highly problem specific.

2.3 SHEPP AND LOGAN FILTER

The study of shepp et al (6) reveals that the Fourier reconstruction may be viewed simply in the spatial domain as the sum of each line integral times a weighting function of the distance from the line to the point of reconstruction.

Ramachandran's linear interpolation is merely the choice of a particular weighting function. A modified weighting function simultaneously achieves accuracy, simplicity, low computation time as well as low sensitivity to noise.

Using a simulated phantom, comparison studies were done on the Fourier algorithm and a search algorithm very similar but notidentical to Housfields algorithm. The search algorithm requires 12 iterations to obtain a reconstruction of accuracy and resolution comparable to that of Fourier reconstruction and more sensitive to noise. To speed the search algorithm using fewer iterations results in error.

The steps similar to Ramachandran's filter derivation are done with the modification in the weighting function.

$$q(0) = 4/\pi a^2 \qquad \text{for} \quad K=0$$

$$q(Ka) = -4/\pi a^2 (4K^2-1) \qquad \text{for} \quad K=\pm 1,2, \ \ldots.$$

This is the Shepp and Logan filter.

2.4 GENERALISED FILTER

In their study Kwoh et al (4) have given a new filter called generalised filter. One general class of digital w - filter without interpolation is defined by

$$W(w) = \begin{cases} \frac{1}{a} |w| \exp - \left| \frac{w}{w_c} \right|^p = \frac{1}{a} w \exp -\zeta |w|^p & w \leq \pi/a \\ \frac{1}{a} \left| \frac{2\pi}{a} - w \right| \exp -\zeta \left| \frac{2\pi}{a} - w \right|^p & \pi/a \leq w \leq \frac{2\pi}{a} \end{cases}$$

where zeta (ζ), $p \geq 0$; a is the sample spacing and W(w) is the periodic with period $2\pi/a$.

Zeta $= \left| \frac{1}{w_c} \right|^p$ is called the damping factor. It is a function of the cut-off frequency w_c and the parameter p. the increased number of parameters over what was used in other filters makes it easier to fit a filter specification.

The portion $\exp\left(- \left| \frac{w}{w_c} \right|^p \right)$ serves as a switch. At low frequencies , it is not triggered and $W(w) = |w|$. For higher frequencies, it switches to zero as w approaches the cut-off frequency w_c. W(w) tends to zero with a rate

depending on the parameters p and w_c. To minimise oscillations it is desirable to choose w_c and p so that a smooth cut off results. This is exactly what that is done. Four such values taken and tested to find which amongst them fit in and give the best of results for the problem in question.

When ξ =0, the generalised filter is identical to the triangular wave filter used by Ramachandran. For certain values of ξ and p, the generalised filter approximates the filter of sheppand logan very (fairly) accurately. For p>1 as in all the four cases considered numerical analysis is used to obtain the response.

$$W(na) = \frac{1}{\pi}\int_0^{\pi/a} w\exp-\xi w^p \text{ Cos } naw \, dw \qquad \text{......(11)}$$

This is the response for n = 0

for other n's. We change variables by putting z=naw.

So that (11) approximates to

$$W(na)= \frac{1}{\pi a^2 n^2}\int_0^{n\pi} z \exp -\xi\left(\frac{z}{an}\right)^p \text{ Cos } z \, dz \text{ for } n=1,2,.. \qquad \text{.....(12)}$$

for n=1 we get,

$$W(a) = \frac{1}{\pi a^2}\int_0^{\pi} z \exp -\xi\left(\frac{z}{a}\right)^p \text{ Cos } z \, dz \qquad \text{.....(13)}$$

for n>1, (12) is put in alternate form

when n is even

$$W(na)=\frac{1}{\pi a^2 n^2}\int_0^{2\pi} \cos z \left(\sum_{j=0}^{\frac{n}{2}-1} (z+2\pi j) \exp\left\{-\zeta\frac{(z+2\pi j)^p}{(an)}\right\} dz\right)$$

when n is odd >1

$$W(na)=\frac{1}{\pi a^2 n^2}\int_0^{2\pi} \cos z \left(\sum_{j=0}^{\frac{n-3}{2}} (Z+2\pi j) \exp -\zeta\frac{(z+2\pi j)^p}{(an)^p} dz\right.$$

$$\left. +\frac{1}{\pi a^2 n^2}\int_0^{\pi} \cos z \left(\left(Z+2\pi\left(\frac{n-1}{2}\right)\right) \exp -\zeta\frac{\left(z+2\pi\frac{(n-1)}{2}\right)^p}{an} dz\right)\right)$$

$W(na) = W(-na)$ for $n= 1,2$ ......

This filter in turn was used with various values for its parameters p and Zeta, which were recommended by Kwoh et al.(4).

P= 2.03399 and Zeta = 2.243E-06 is the approximation of a generalised filter to Shepp and Logan filter.

P= 1.2 and Zeta=5E-04 is the approximation between Shepp and Logan and parabolic filter.

P=2.0 and Zeta=3E-05 best minimized the internal undershoot while preserving the shape of the object.

P=2.6 and Zeta=0.96E-05 was also used.

2.5 PARABOLIC FILTER

The parabolic filter is an approximation of certain parameters of a generalised filter and particular value of p and Zeta (ζ).

The filter has response of

$$W(0)= \frac{\pi}{3a^2} \qquad \text{for } n=0$$

$$W(na)= \frac{-1}{\pi(na)^2} \qquad \text{for } n= \pm 1, \pm 2 \quad ....$$

$$W(w)= \frac{1}{a}\left\{ |w| - \frac{a}{2\pi} w^2 \right\} \quad 0 \leq w \leq \frac{2}{a}$$

is the frequency response of a parabolic filter.

2.6 Filter used :

Three dimensional (3D) reconstruction for diverging X-ray/Gamma ray beams as studied by Kwoh et al (7)has shown that fast digital convolution technique is extended to diverging X-ray/Gamma ray beams by suitable changes to parallel X-ray/Gamma ray beams conditions. This along with the generalised $|w|$filter yields good accuracy and excellent results. It also has a flexibility to cope with noise and substantial reduction in X-ray dosage.

The background for this work is based on Bracewell and Riddle who first suggested Fourier Transform (F.T) might be used to reconstruct an object and that X-ray scanning replaced 3D object by a series of 2D cross-section of the object. Then Ramachandran and Laxminarayan's work and their significance already discussed have improved the situation further by introducing convolution.

The key equations are

$$f(x,y) = \frac{1}{(2\pi)^2}\int_0^{\pi} d\theta \int_{-\infty}^{\infty} |w|\, dw\; p(w,\theta)\, \exp(iw(x\cos\theta + y\sin\theta)) \quad ..(14)$$

w is spatial frequency and $p(w,\theta)$ is F.T. of projection data for parallel beams.

$$b(t,\theta) = \frac{1}{2\pi}\int_{-\infty}^{\infty} |w|\, p(w,\theta)\, \exp((wt))\, dw \quad ..(15)$$

$t = x\cos\theta + y\sin\theta$, $b(t,\theta)$ is called the back projection formula. By the convolution property of the F.T

$$b(t,\theta) = \quad p(\xi,\theta)\, w(t-\xi)\, d\xi \quad ...(16)$$

where $p(t,\theta)$ and $w(t)$ are respectively inverse F.T of $p(w,\theta)$ and $|w|$.

The inverse F.T of $|w|$ does not converge so (16) is valid only in a limiting sense. Since most of the objects have spatial frequency of interest only below some cut-off

frequency w_c, we can replace w with a function $W(w)$ which approximate $|w|$ for $w<w_c$ and zero for $w>w_c$. The class of functions $W(w)$ with these properties are called $|w|$ functions. This is exactly the generalised filter function.

CHAPTER-3

PROGRAM DESCRIPTION

3.1 Overview:

The application of the concept of computerized tomography scanning in two-phase flow problems results in absolute point density values in the pipe cross section averaged over time. The program involves four basic steps which include data input, adjustment of data, reduction and finally the reconstruction of the density map.

The data were taken from Kulacki et al (1) and was in the form of a fan beam geometry. Data was taken at every 2.5 degrees for a total of 50 degrees. The normalised counts were denoted by $h(\lambda, \beta)$, refer Fig. 3.1

where,

$$\beta = i\alpha \qquad \text{for} \quad 0 \leqslant i \leqslant N$$

$$\lambda = Sa \qquad \text{for} \quad -\frac{M}{2} \leqslant s \leqslant \frac{M}{2},$$

M is the number of diverging beams in the fan

N is the number of scans

$a = 2\lambda_{max}/M$,

and $\alpha = \pi/N$

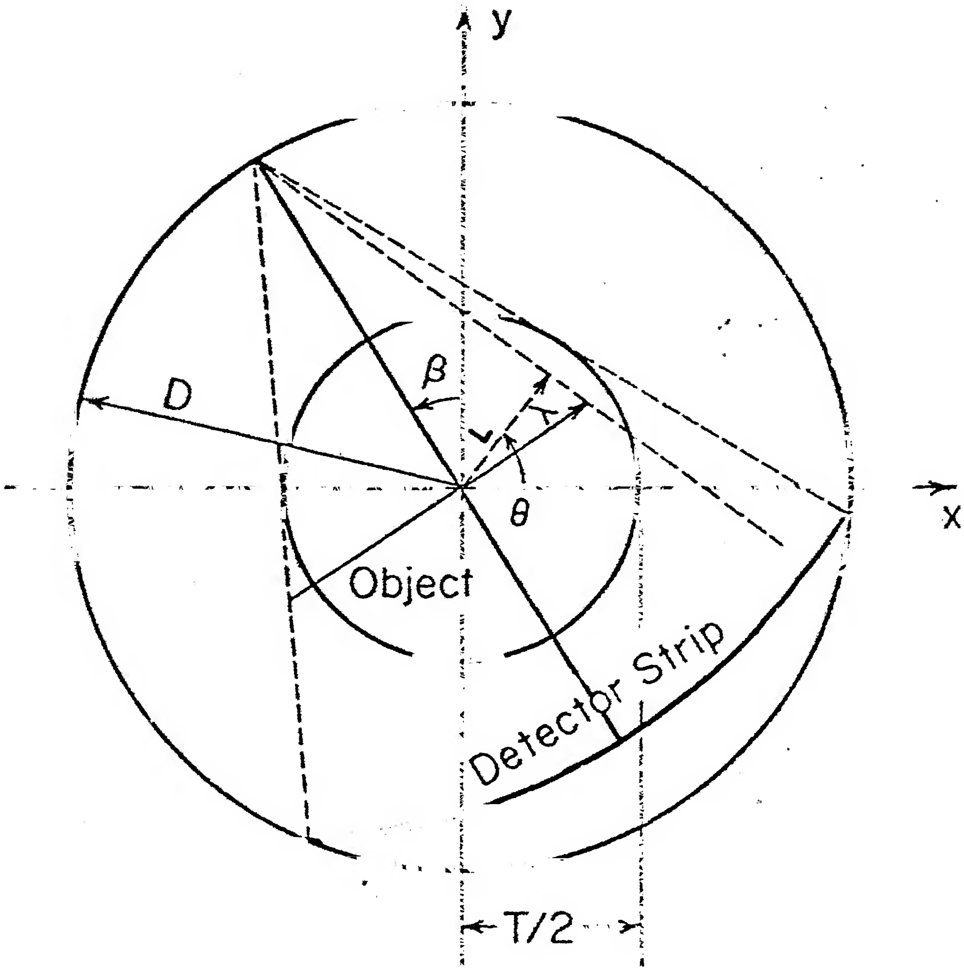


Figure 3.1 Conversion of Fan-Beam Data to Parallel Geometry.

Since the tomography concept is applicable only to the parallel beam case, the fan beam data has to be transformed. The transformed input, $p(L,\theta)$ was determined by

$$\lambda = \frac{1}{\sqrt{1-(L/D)^2}} \qquad \beta = \theta - \sin^{-1}(L/D), \tag{3.1}$$

$$\text{and } p(1,\theta) = h(\lambda,\beta) = h\left(\frac{1}{\sqrt{1-(L/D)^2}},\ \theta - \sin^{-1}\left(\frac{L}{D}\right)\right) \tag{3.2}$$

equation (3.2) involves the lengths L,D and λ , and angles θ and β , which are defined in Fig. (3.1).

The third step involves the use of a filter function, W and the computation of the convolution C (la).

$$C(La) \triangleq \sum_{K=-\frac{M}{2}}^{M/2} p(t_k,\theta)\, W(t_L - t_k)$$

where,

θ_i is the j^{th} angular position

$t_i = ia$ for i= j, k,L,

j,k,L are all integers,

$t_j = X \cos\theta_i + Y \sin\theta_i$

Once $C(t_L,\theta_i)$ is known, the back projection, b and can be determined.

$$b\,(t,\theta_i) = a\ \frac{t_{L+1}-t}{t_{L+1}-t_L}\ C(t_L,\theta_i) + \frac{t-t_L}{t_{L+1}-t_L}\ C(t_{L+1},\theta_i)$$

and finally the reconstructed density function f(x, y) is

$$f(x,y) = \frac{1}{2N} \sum_{i=0}^{N-1} b(t,\theta_i),\ 0 \leqslant i \leqslant N-1$$

The print out of the program is enclosed in Appendix A

3.2 Steps involved :

The essential steps involved were as follows ?
The input data was given in the proper format along with source to center distance (D), diameter of the object (T) Number of scans and number of projections in scan (M), etc. Then this was supplemented with LITM and N and a conversion to parallel beam done, along with interpolation to increase the number of data points.

Then the next step was in choosing the filter function. Schlosser et al (2) in their study have amply proved that Shepp and Logan filter is simple and good enough to the data used. This is verified and Parbolic filter and four cases of generalised filter are also taken up.

The generalised filter was calculated using integration routines and this was done with a limited accuracy. There were four integrations to perform to calculate separately values for N=O , 1, odd and even.

This shows as to why generalised filter was not used by Kulacki et al (1). The calculation of generalised filter is really a cumbersome process involving four integrations. Four types of generalised filters were considered depending upon which other common types then approximated to. There were four values of p and ZETA chosen and they are as follows.

1. P= 2.0 and Zeta= 1.07E-02

2. P= 2.0 and Zeta= 4.28E-02

3. P= 2.0 and Zeta= 4.75E-03

4. P= 2.0 and Zeta= 2.67E-03

These values of filter were used and Convolution found. Then Superimposition and Printing done in the proper format and LITF directly gives density values.

3.4 Data used:

The Data was taken from the study conducted by Kulacki et al(1). The source of nuclear radiation was 13.86 mCi of Cs-137 and fixed. The Collimator fixed at the other end was rotated through and angle of 50° (25° on each side).

The Detector was connected to this and the readings taken through preamplifier, amplifier, baseline restorer, Single channel analyser and a timer.

The Data was collected for eight various materials. Four of them water, air, walnut and pine are used for calibration.purpose. The other four 90% density, 80% density, 70% density and 60% density were taken for six types of scans and calculated and drawn accordingly on the graph.

CHAPTER-4

RESULTS

4.1 THEORITICAL CONSIDERATIONS

Density measurements in two-phase flow via the techniques used in axial computerized Tomography involves the data output format, interpretation of output and calibration of the computer algorithm. In each area the problem of relating what the reconstruction calculation means both physically and mathematically must be addressed. The data obtained in the present study is interpreted and best utilized for the overall objective of the investigation.

INTERPRETATION OF DATA OUTPUT

A typical reconstruction output appears in Matrix form shown in Fig. 4.0. The elements of this output Matrix vary from 0 to 99. At the bottom of the picture are indicated the maximum and minimum values of 'LITF'. This variable, LITF, is related to point density values. In fact, each number corresponds to the density of unit cell around it. Linear interpolution is used to reduce

63	66	[illegible]	[illegible]	72	76	81	[illegible]	86	89	[illegible]	88	83	82	[illegible]	96	85	82	87	78	76	74	73	73	76	81	82	85	87	89	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	64	53
65	65	[illegible]	72	59	74	79	86	89	[illegible]	83	82	86	83	79	73	67	63	67	[illegible]	57	54	54	62	63	51	63	57	74	80	84	93	[illegible]	[illegible]	[illegible]	77	[illegible]	71	[illegible]	[illegible]	59
61	62	64	71	75	83	87	87	83	77	83	81	73	64	65	70	43	44	[illegible]	37	37	33	30	32	35	51	50	62	50	54	78	95	[illegible]	69	[illegible]	75	[illegible]	70	67	67	69
72	72	75	[illegible]	83	87	82	81	83	64	73	62	59	41	36	41	32	31	30	29	29	29	30	32	31	37	40	15	51	54	75	59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	72	[illegible]	72	[illegible]
71	69	79	[illegible]	70	91	79	64	60	66	53	41	35	32	30	28	26	21	23	23	23	22	23	21	25	27	31	31	39	16	[illegible]	54	[illegible]	75	[illegible]	[illegible]	[illegible]	[illegible]	77	[illegible]	[illegible]
75	78	84	87	[illegible]	81	63	77	51	37	33	34	30	27	23	22	21	20	13	13	12	13	19	19	20	21	23	25	24	17	49	51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
80	78	87	95	79	93	75	58	42	35	31	27	23	21	19	17	16	15	14	13	11	11	15	15	17	13	10	20	22	26	34	47	17	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
81	85	87	61	84	77	55	42	34	30	25	22	19	17	15	14	13	13	12	12	12	12	12	13	11	15	13	13	11	23	25	49	35	56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
55	88	83	83	80	61	42	34	24	24	21	18	15	14	13	12	11	10	10	10	10	9	10	10	11	12	10	13	11	19	24	26	23	37	17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
89	69	77	64	66	47	35	30	25	21	18	15	13	12	11	10	9	9	8	8	8	8	8	8	9	9	10	12	11	10	15	20	21	30	[illegible]	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	87	83	73	53	37	31	26	21	18	15	13	12	11	9	8	7	7	6	6	6	6	6	5	7	7	7	9	11	13	16	18	21	21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
88	81	82	62	41	33	27	22	18	15	13	12	10	9	8	7	6	5	5	4	4	4	3	4	5	5	6	7	8	9	11	11	14	16	16	19	21	[illegible]	[illegible]	[illegible]	[illegible]
83	85	73	51	35	30	24	20	16	13	12	10	9	8	6	5	5	4	4	3	3	3	3	3	4	4	5	6	7	7	11	13	15	19	22	20	31	52	65	75	61
87	84	63	42	33	27	22	17	14	13	11	9	8	6	5	4	3	3	2	2	2	2	2	2	3	3	3	5	6	7	0	12	15	17	19	25	34	46	61	54	69
83	78	55	37	30	24	22	15	13	12	10	9	7	5	4	3	2	2	2	1	1	1	1	1	2	2	2	4	4	5	9	10	13	16	17	22	30	40	54	65	81
85	72	48	33	28	22	18	14	13	11	9	7	6	5	3	2	1	1	1	1	1	1	1	1	1	2	2	3	4	5	9	11	15	18	21	27	44	52	55	75	[illegible]
85	66	43	33	26	21	15	14	12	10	8	6	5	3	2	1	1	1	1	1	1	1	1	1	1	2	2	3	[illegible]	6	8	10	14	17	20	25	31	47	[illegible]	69	[illegible]
83	62	39	31	25	20	15	13	11	9	7	6	4	2	2	1	1	1	1	1	1	1	1	1	1	1	2	3	4	5	7	9	12	16	19	21	32	41	63	[illegible]	[illegible]
83	59	39	31	24	19	15	13	11	9	7	5	3	2	1	1	1	1	1	1	0	1	1	1	1	1	2	2	4	5	7	9	12	15	19	22	30	41	61	65	[illegible]
82	57	37	30	23	19	15	13	10	8	7	5	3	2	1	1	1	1	0	0	0	1	1	1	1	1	2	2	[illegible]	5	7	9	11	15	[illegible]	22	40	41	40	61	[illegible]
80	56	36	30	23	19	14	12	10	8	7	5	3	2	1	1	1	1	0	0	0	1	1	1	1	1	2	2	3	5	7	9	11	15	14	22	20	21	59	65	[illegible]
82	57	37	30	23	19	15	13	10	8	7	5	3	2	1	1	1	1	0	0	0	1	1	1	1	1	2	2	4	5	7	9	11	15	18	22	30	40	61	63	[illegible]
83	59	38	31	24	19	15	13	11	9	7	5	3	2	1	1	1	1	1	0	0	1	1	1	1	1	1	2	3	4	5	7	9	12	15	18	22	30	31	61	65
83	62	40	31	25	20	15	13	11	9	7	6	4	2	2	1	1	1	1	0	1	1	1	1	1	1	1	2	3	4	5	7	9	13	16	19	23	32	34	63	65
85	66	43	33	26	21	15	14	12	10	8	6	5	3	2	1	1	1	1	1	1	1	1	1	1	1	2	2	3	5	6	8	10	13	17	20	25	34	37	54	70
85	72	48	34	28	22	18	14	13	11	9	7	6	4	3	2	1	1	1	1	1	1	1	1	1	1	2	2	4	[illegible]	7	9	11	15	19	21	27	36	52	65	75
83	78	55	37	30	24	19	15	13	11	10	8	7	5	4	3	2	2	1	1	1	1	1	1	2	2	3	4	5	[illegible]	[illegible]	10	13	16	19	22	31	[illegible]	53	55	81
82	84	63	42	33	27	21	17	14	13	11	9	8	6	5	4	3	2	2	2	2	2	2	2	2	3	4	5	6	7	[illegible]	11	14	17	20	25	[illegible]	46	54	63	99
83	85	73	51	35	30	24	19	16	13	12	10	9	8	6	5	4	3	3	3	3	3	3	3	3	4	5	6	7	9	11	13	15	19	22	29	[illegible]	51	65	75	91
88	81	81	62	41	33	27	22	18	15	13	12	10	9	8	7	5	5	5	4	4	4	4	4	5	5	6	7	9	11	14	16	19	21	26	34	45	53	55	[illegible]	91
90	82	83	73	52	36	31	25	21	17	14	13	12	10	9	8	7	7	6	6	6	6	6	6	5	7	8	9	11	13	15	18	24	24	31	[illegible]	55	[illegible]	74	93	67
88	89	77	84	66	47	35	30	21	21	17	15	13	12	11	10	9	8	8	8	7	7	7	8	8	8	9	10	12	14	15	18	20	21	33	38	50	[illegible]	68	46	[illegible]
85	88	83	83	80	60	42	34	23	24	21	18	15	14	13	12	11	10	10	10	9	9	10	10	11	12	13	15	17	18	20	23	29	36	37	52	55	40	73	95	77
82	85	87	62	84	77	59	42	34	30	25	22	19	17	15	11	13	13	12	12	12	12	12	12	13	14	15	17	19	19	21	24	40	37	[illegible]	61	65	75	92	41	85	76
90	79	86	90	79	94	75	58	43	35	31	27	24	22	19	19	16	16	15	15	15	15	15	16	16	17	18	19	21	23	28	32	38	37	51	55	73	[illegible]	95	[illegible]	37	72
74	78	84	87	86	81	83	77	60	46	35	33	29	26	24	22	21	20	19	18	18	18	18	18	19	20	21	22	25	23	34	41	50	62	55	72	91	93	92	75	78	69
76	69	78	82	99	86	79	84	80	65	52	41	35	32	30	27	25	24	23	22	22	22	22	23	21	25	27	30	34	38	45	56	64	55	75	82	33	43	83	77	74	59
72	72	75	79	83	88	90	92	83	91	71	62	51	42	37	31	33	31	30	30	30	30	30	31	32	31	37	40	36	54	53	61	88	70	82	95	92	83	73	71	70	60
62	63	65	76	79	85	88	88	84	75	84	83	74	64	56	49	44	41	39	39	38	39	38	39	41	43	47	57	58	63	65	50	71	97	91	91	47	76	77	72	61	69	60
65	66	62	72	69	79	77	86	39	39	83	82	86	85	79	73	67	63	60	58	57	58	57	58	60	62	63	64	65	67	75	95	93	94	94	85	86	77	74	71	64	58	53
56	59	55	66	65	69	74	75	79	82	84	83	77	75	77	79	78	75	74	72	69	59	67	66	59	74	81	89	90	92	87	85	75	75	71	57	67	59	59	58	47

MINIMUM LITF= 0.39390406E+00-MAXIMUM LITF= 0.16877237E+01

14.90114 , 14320.00 , 961.

These are the values for Scan Six 60% Density or 40% Void (o=0.6) for P=2.0 and Zeta for any values(1)

LITF = 0.59

the actual values of LITF within a range of 0 to 99.

Since the quantify of interest is the horizontally averaged density, $\langle\rho\rangle$, the cross-sectional average of LITF is required. Thus ⟨LITF⟩ is the sum of the values of LITF over the cross-section divided by the number of unit cells present.

The algorithm output is a 40x40 Matrix while the, pipe wall effects prevents any reasonable values to be had above 31 units. Hence 31 x 31 Matrix is considered good and used for averaging and finding 'LITF'.

$$\text{LITF} = \frac{\sum_{i=1}^{961} \text{LITF}}{961} \qquad \ldots(4.1)$$

where 961 is (31x31) the total number of unit cells.

The reconstruction accuracy for Shepp and Logan filter is around $\pm$ 10% . The accuracy for generalized filter is around $\pm$ 4%.

CALIBRATION

The quantity ⟨LITF⟩ determined by equation (4.1) corresponds to the actual density values across the flow area. Scans for the cases of Water (ρ=1.0 g/cm), Air($\rho \simeq$ approximately zero g/cm), Walnut (ρ=0.73 g/cm) and Pine (ρ=0.41 g/cm)

result in four different values of LITF for known densities. Since these known densities are accurate within $\pm$ 0.5% a reasonably good plot of LITF verses ρ is achieved. Densities are read off directly from this calibration curve once LITF is known. The above calibration was used for six types of filters viz:-

1. Shepp and Logan filter
2. Parabolic filter and
3. Four cases of Generalised filter.

A comparison of calibration curve can be made and some interesting points noted.

Ramachandran filter was also used and found unsuitable for the present study. Similar observations were made by Kulacki et al (1) in their study of filters.

Figures (4.1) through (4.6) represent calibration for different filters used. Fig.(4.1) is for the Shepp and Logan filter which can be compared to that obtained by Schlosser et al (2). Fig. (4.2) represents calibration for parabolic filter and Fig.(43) to (4.6) for four different cases of Generalised filter (sec. 2.4).

Table 4.1 Calibration of LITF using Shepp & Logan Filter

Case	ρ	LITF
Water	1.0	1.075
Walnut	0.73	0.6986
Pine	0.41	0.351
Air	0.0	0.0966

Table 4.2 Calibration of LITF using Parabolic Filter

Case	ρ	LITF
Water		
Water	1.0	0.751
Walnut	0.73	0.480
Pine	0.4	0.222
Air	0.0	0.08

Table 4.3 Calibration of LITF using Generalised Filter

Case	ρ	Gen 1	Gen 2	Gen 3	Gen 4
Water	1.0	0.924	0.915	0.926	0.928
Walnut	0.73	0.736	0.728	0.682	0.74
Pine	0.41	0.489	0.483	0.491	0.492
Air	0.0	0.0	0.0	0.0	0.0

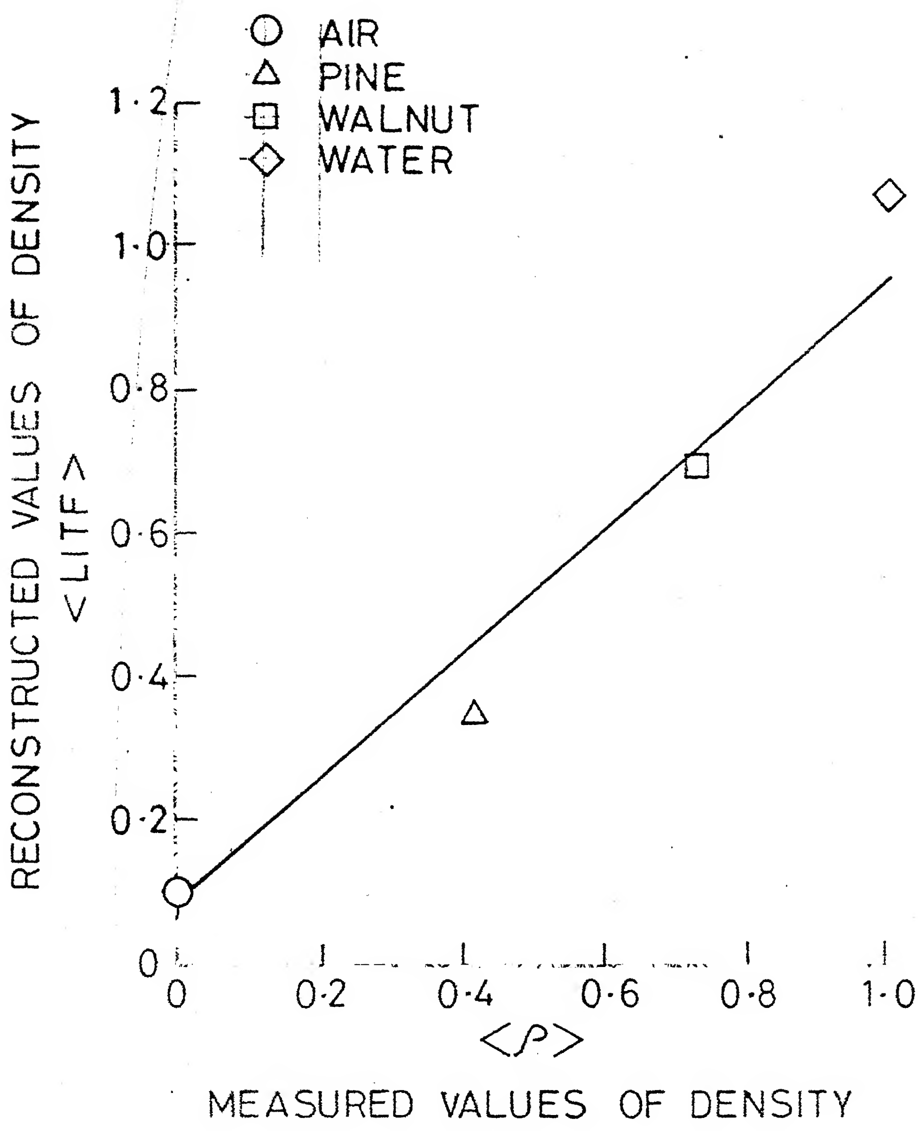


FIG. 4·1 CALIBRATION OF SHEPP AND LOGAN FILTER

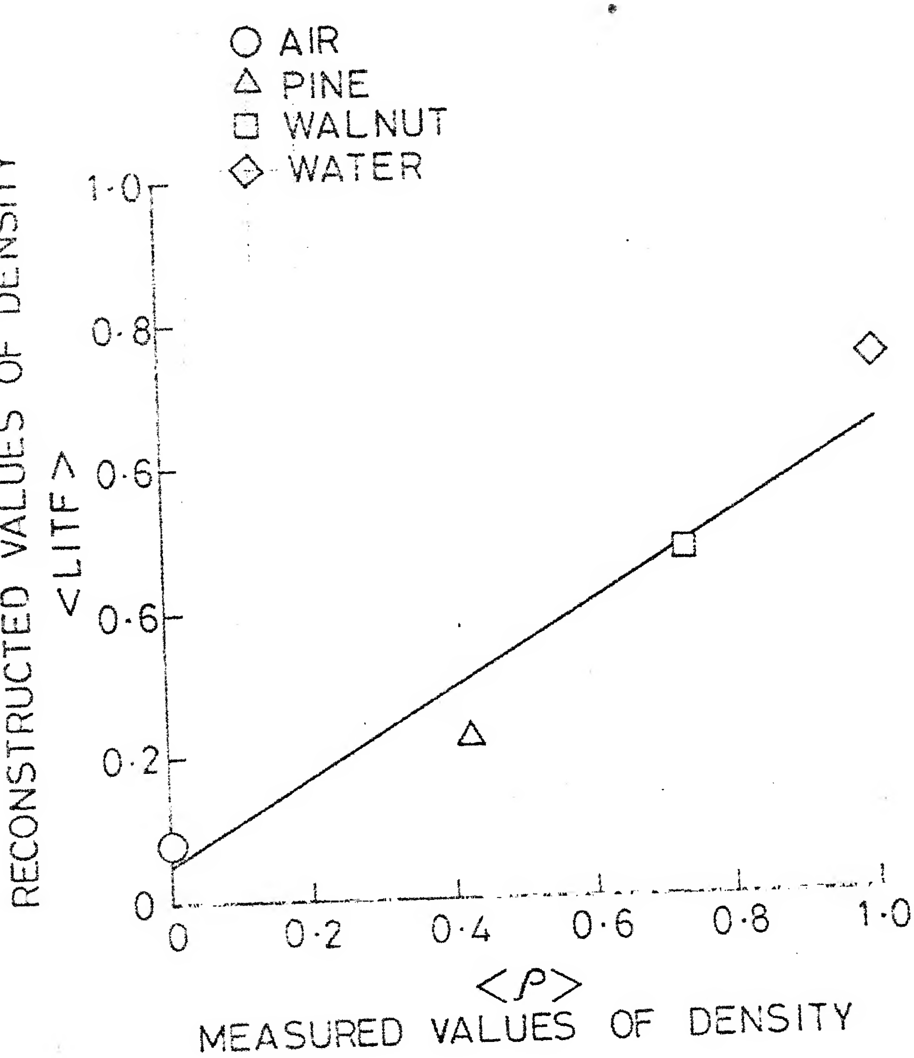


FIG. 4·2 CALIBRATION OF PARABOLIC FILTER

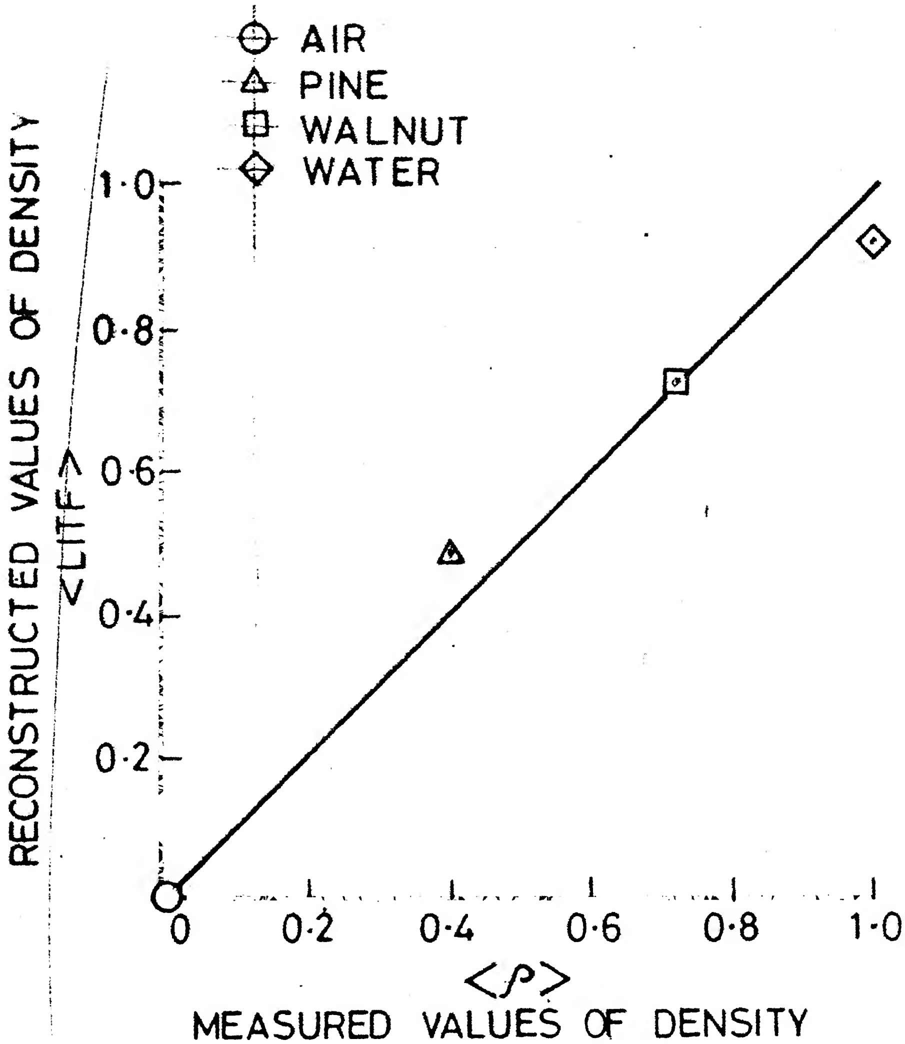


FIG. 4·3 CALIBRATION OF GENERALISED FILTER NO

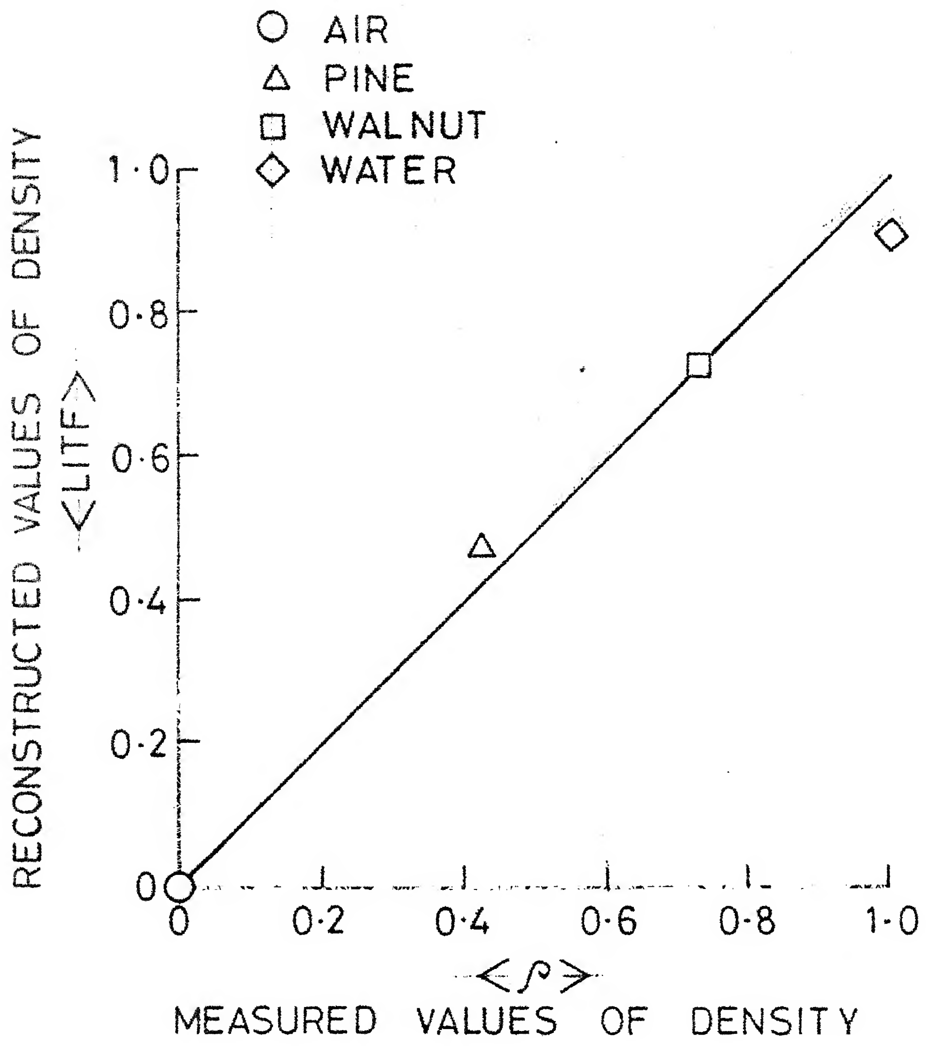


FIG. 4·4 CALIBRATION OF GENERALISED FILTER NO.1

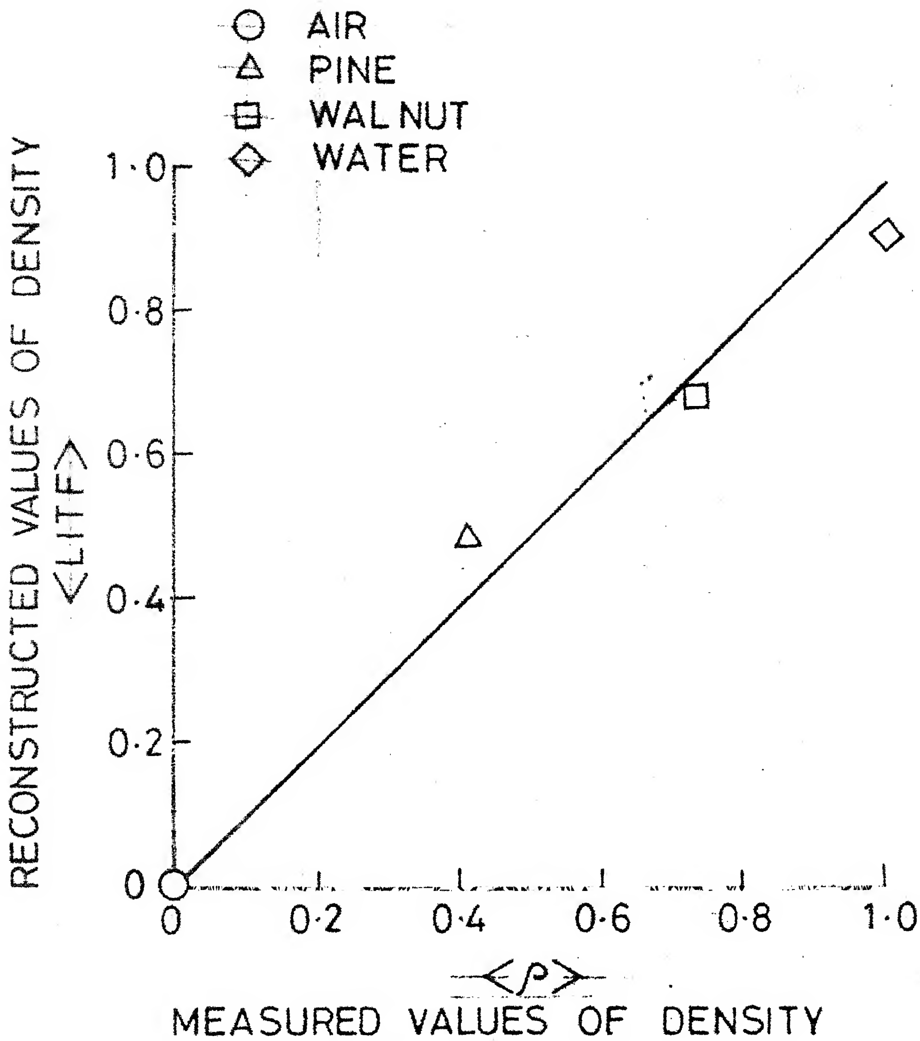


FIG. 4·5 CALIBRATION OF GENERALISED FILTER NO.3

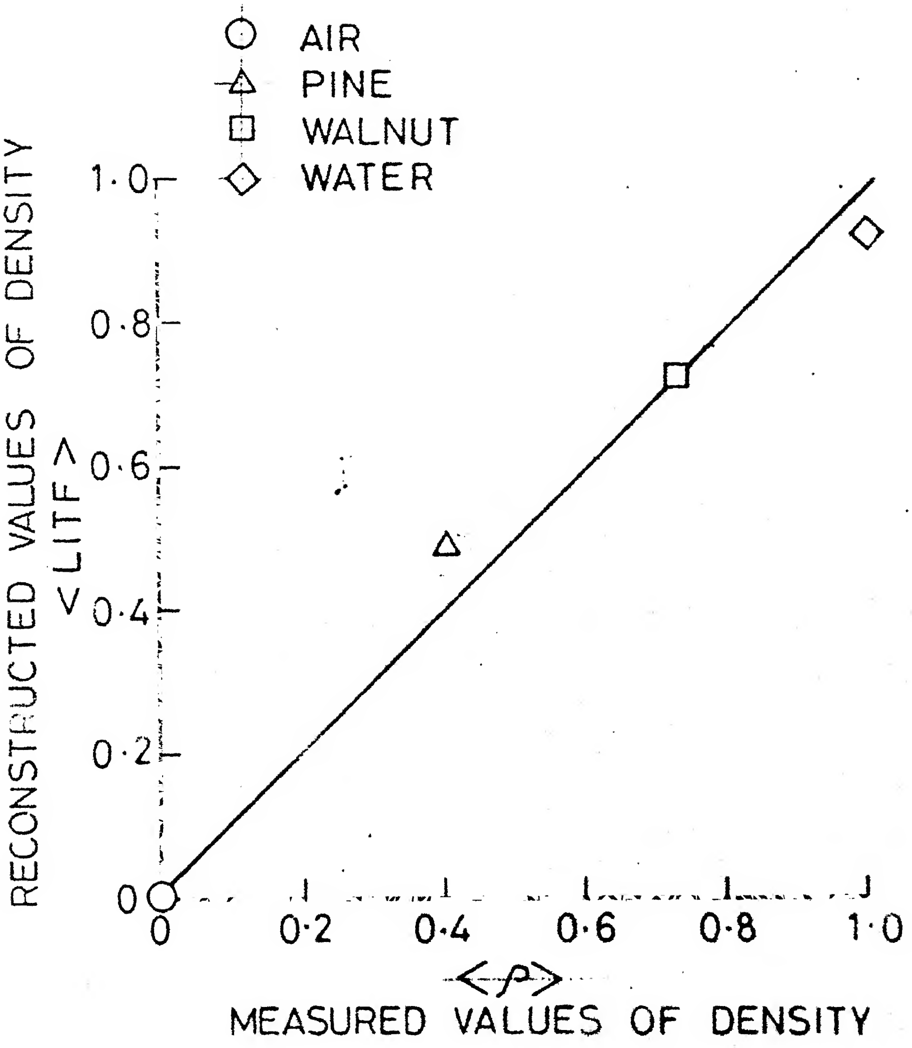


FIG.4-6 CALIBRATION OF GENERALISED FILTER NO. 4

Table 4.4 Values of LITF for various scans for Shepp and Logan filter

Scan No. \ D	0.9	0.8	0.7	0.6	
1	1.15	0.97	0.93	0.71	
2	0.97	0.91	0.85	0.74	
3	1.02	1.05	0.83	0.90	Rejected
4	1.01	0.96	0.88	0.74	
6	1.23	1.03	0.86	0.73	

Table 4.5 Values of LITF for various scans for Parabolic Filter

Scan No. \ ρ	0.9	0.8	0.7	0.6	
1	0.84	0.7	0.69	0.52	
2	0.69	0.66	0.62	0.55	
3	0.73	0.77	0.61	0.68	Rejected
4	0.72	0.7	0.66	0.56	
6	0.91	0.76	0.63	0.54	

Table 4.6 Values of LITF for various scans for Generalised Filter Number 1

Scan No \ ρ	0.9	0.8	0.7	0.6
1	0.82	0.76	0.684	0.573
2	0.81	0.744	0.67	0.57
3	0.813	0.74	0.643	0.564
4	0.824	0.75	0.66	0.543
6	0.84	0.77	0.694	0.584

Table 4.7 Values of LITF for various scans for Generalised Filter number 2

Scan No \ ρ	0.9	0.8	0.7	0.6
1	0.81	0.75	0.68	0.57
2	0.804	0.74	0.66	0.56
3	0.81	0.74	0.64	0.56
4	0.82	0.74	0.65	0.54
6	0.83	0.76	0.69	0.58

Table 4.8 Values of LITF for various scans for Generalised Filter number 3

ρ / Scan No.	0.9	0.8	0.7	0.6
1	0.823	0.76	0.69	0.58
2	0.82	0.76	0.672	0.57
3	0.82	0.75	0.65	0.57
4	0.825	0.755	0.663	0.55
6.	0.84	0.775	0.7	0.59

Table 4.9 Values of LITF for various scans for Generalised Filter number 4

ρ / Scan No.	0.9	0.8	0.7	0.6
1	0.83	0.765	0.69	0.58
2	0.82	0.753	0.676	0.574
3	0.823	0.75	0.652	0.572
4	0.833	0.76	0.667	0.546
6	0.843	0.779	0.70	0.59

Table 4.10 Errors obtained for different scans (Gen 4)

Scan No.	$\langle \rho \rangle=0.9$	$\langle \rho \rangle=0.8$	$\langle \rho \rangle=0.7$	$\langle \rho \rangle=0.6$
1	0.07	0.03	0.01	0.02
2	0.08	0.05	0.02	0.02
3	0.08	0.05	0.05	0.03
4	0.07	0.03	0.03	0.04
6	0.06	0.02	0.0	0.01

Table 4.11 Relative errors Vs ρ (Gen 4)

$\langle \rho \rangle$	$\Delta \langle \rho \rangle$	$\Delta \langle \rho \rangle / \langle \rho \rangle$
0.9	0.072	0.08
0.8	0.036	0.045
0.7	0.023	0.033
0.6	0.02	0.030

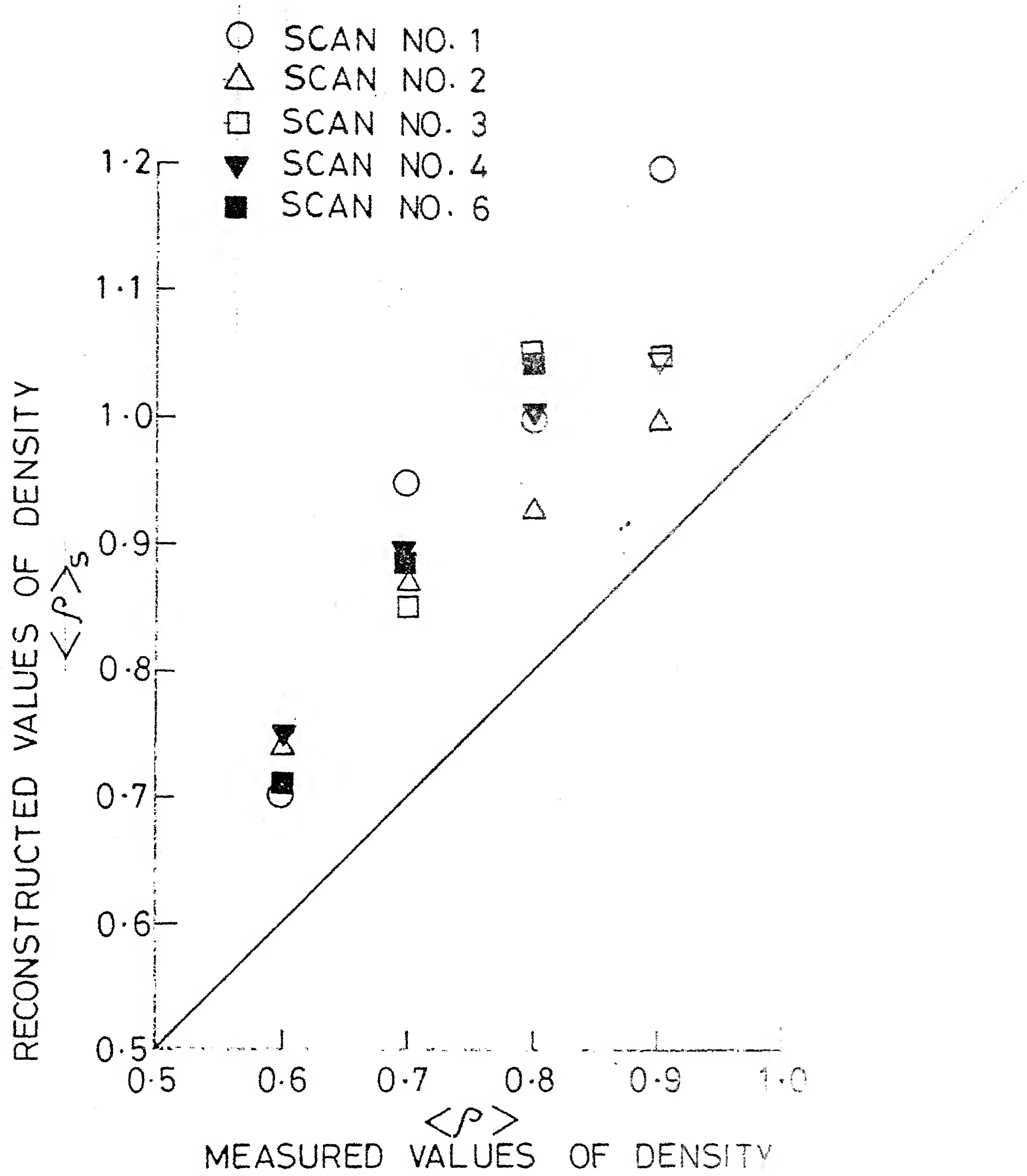


FIG. 4·7 COMPARISON BY SHEPP AND LOGAN FILTER OF ACTUAL DENSITY AND DENSITY FROM CAT SCAN

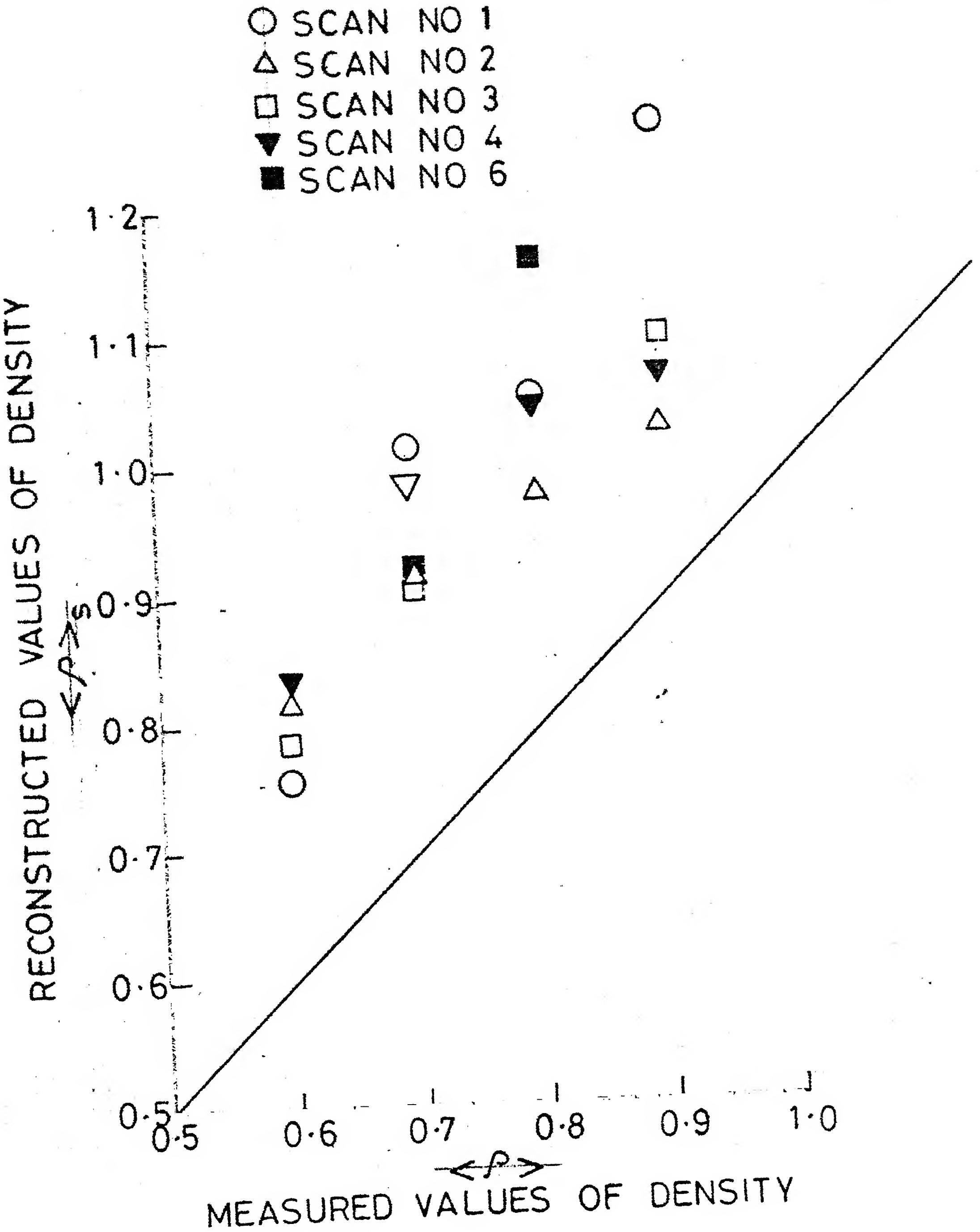


FIG. 4·8 COMPARISON BY PARABOLIC FILTER OF ACTUAL DENSITY AND DENSITY FROM CAT SCAN

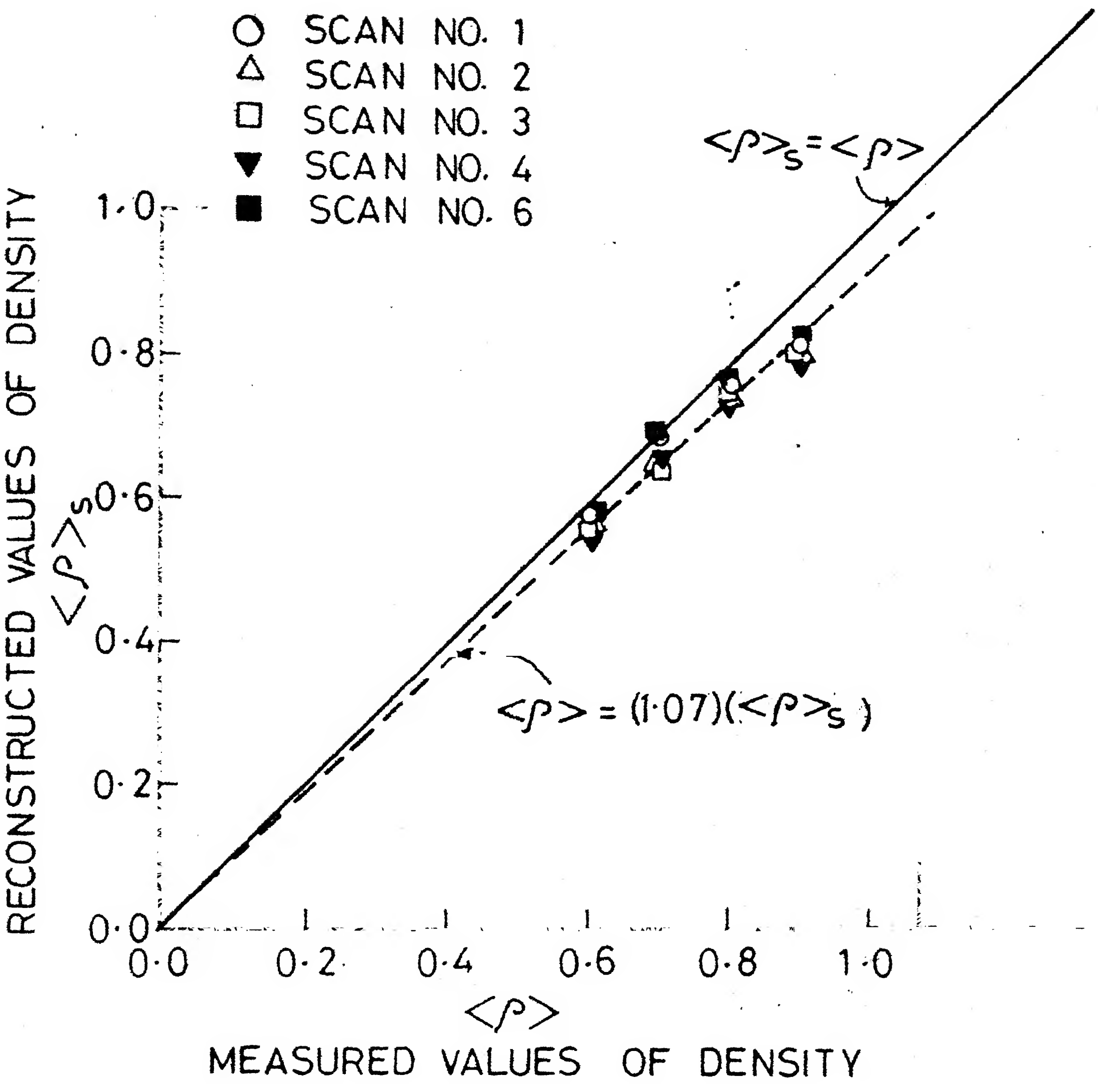


FIG. 4·9 COMPARISON BY GENERALISED FILTER NO. 1 OF ACTUAL DENSITY AND DENSITY FROM CAT SCAN

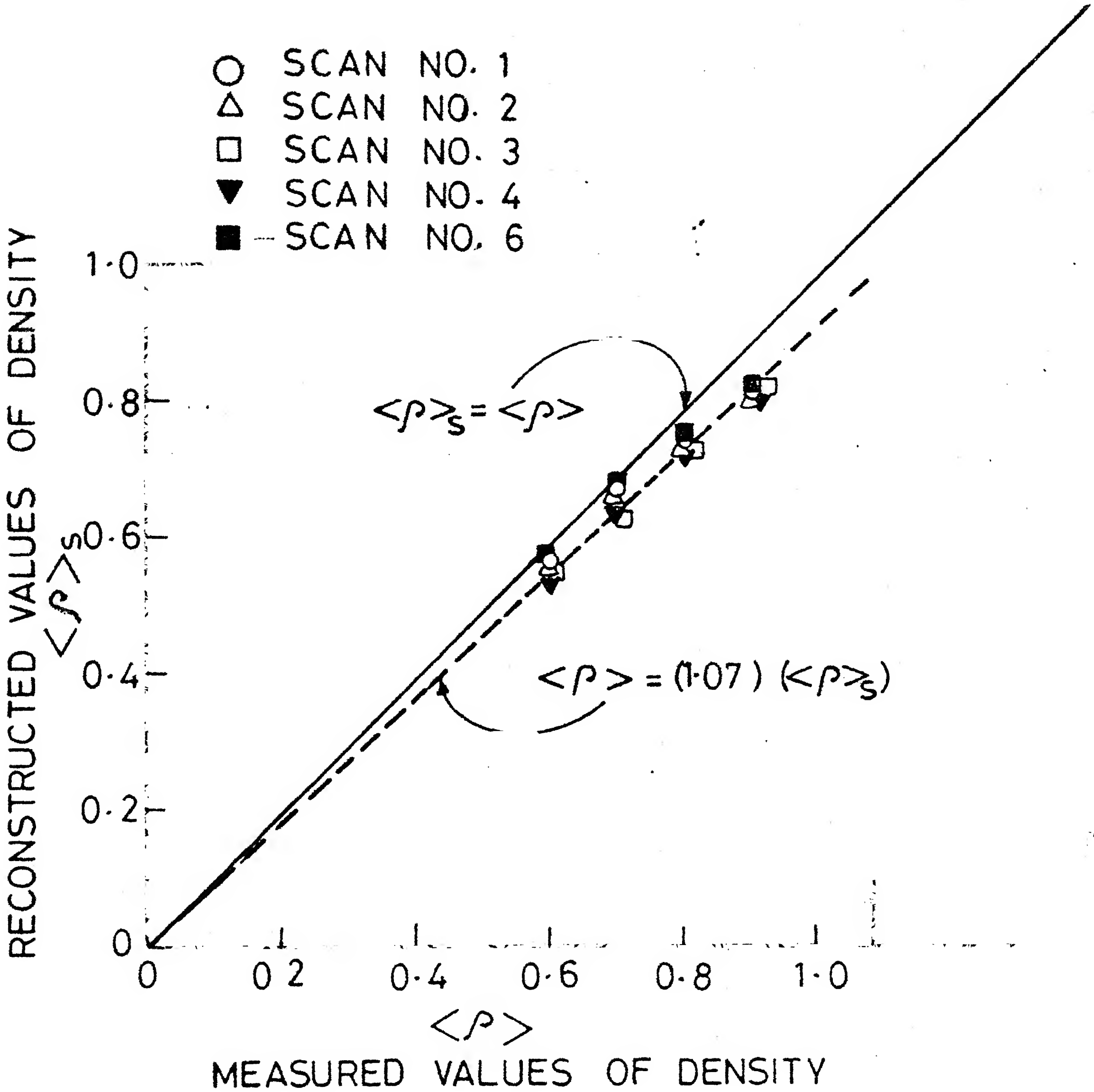
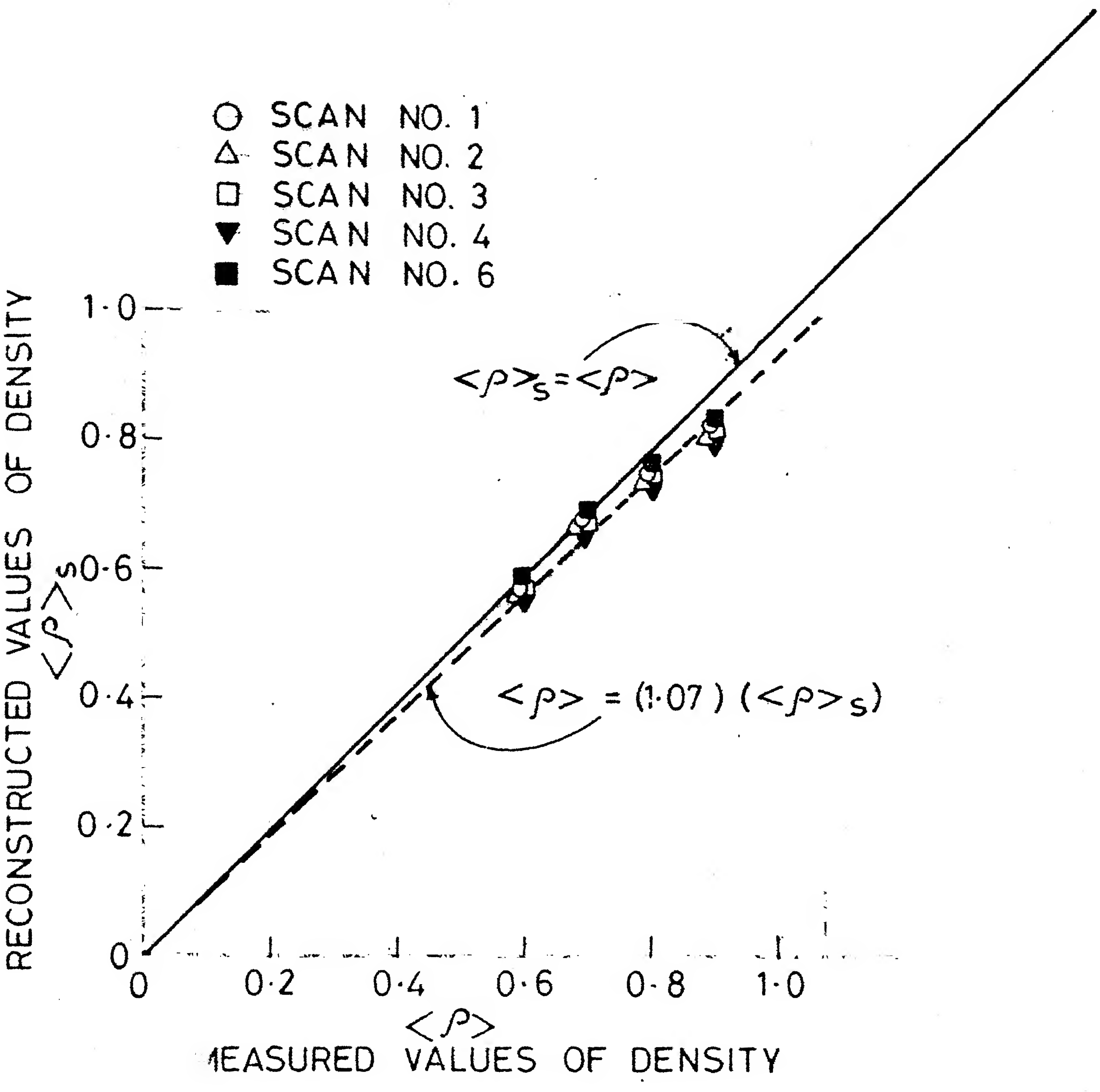


FIG. 4·10 COMPARISON BY GENERALISED FILTER NO. 2 OF ACTUAL DENSITY AND DENSITY FROM CAT SCAN



G. 4·11 COMPARISON BY GENERALISED FILTER NO. 3 OF ACTUAL DENSITY AND DENSITY FROM CAT SCAN

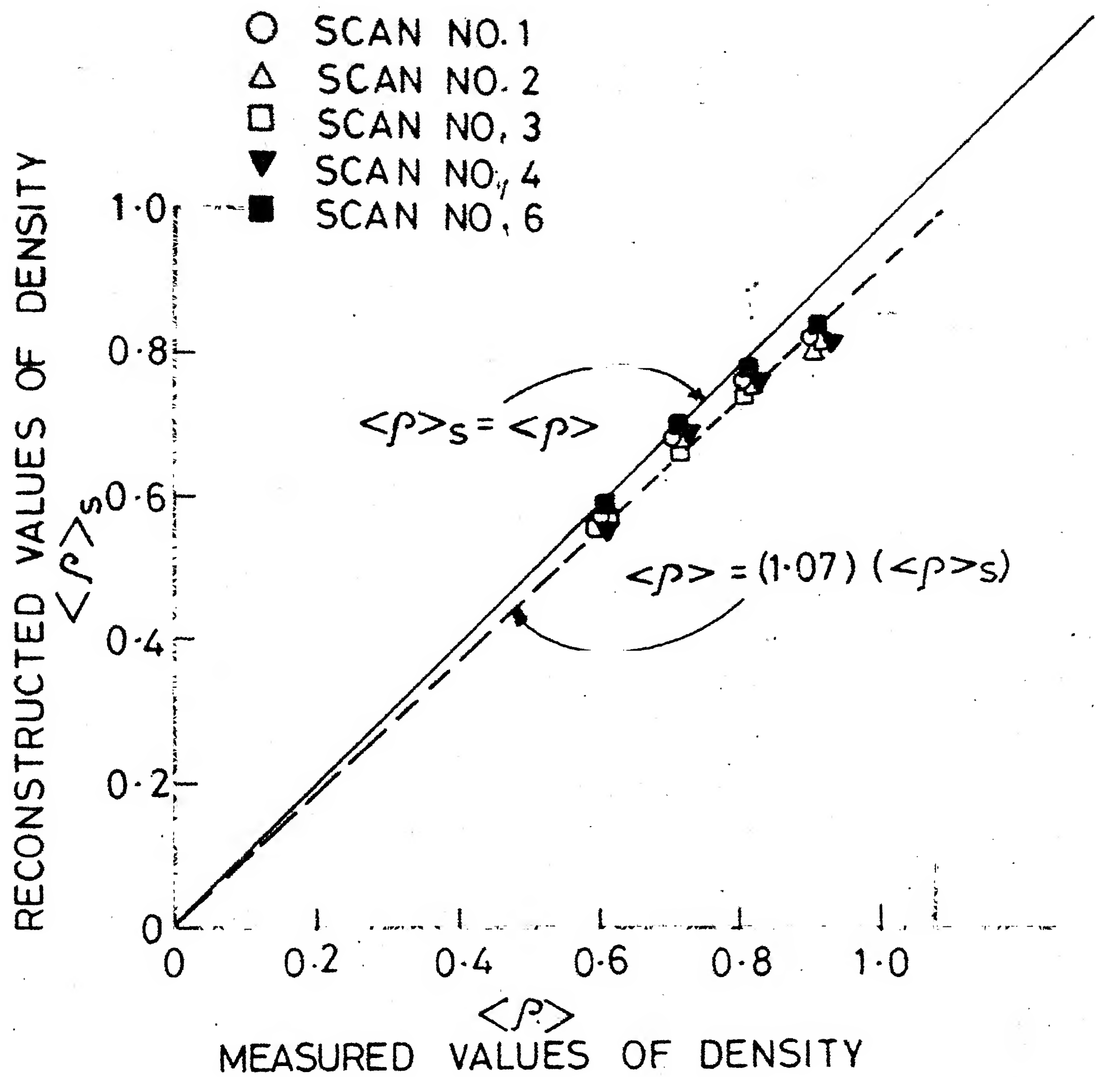


FIG. 4·12 COMPARISON BY GENERALISED FILTER NO. 4 OF ACTUAL DENSITY AND DENSITY FROM CAT SCAN

Tables (4.4 to 4.9) show the reconstructed density values for various scans and for various filters. Fig.(4.7) to (4.12) includes a comparision of the cross sectionally averaged values of density by the scan method to other method, denoted by $\langle \rho \rangle_s$ and $\langle \rho \rangle$ respectively.

The darkline indicates a perfect match between the values of density measured by the two different methods. A noticeable feature in Fig. (4.7) and (4.8) is that the values of $\langle \rho \rangle_s$ are greater than the values of $\langle \rho \rangle$ for all the scans. However, for all the cases of the generalised filter (Fig. 4.9 to 4.12) we see a considerable improvement in in the LITF values compared to those of the Shepp and Logan, and the parabolic filters.

Table (4.10) summarize the deviations of $\langle \rho \rangle_s$ values from the $\langle \rho \rangle$ values. Fig. (4.13) represent Table (4.10) in a graphical form. There is an underestimation of true values by the reconstructed density values as can be clearly made out in Figs.(4.9 to 4.12) . The difference $\delta \langle \rho \rangle$, between these two values follows a pattern with width of $\Delta \langle \rho \rangle$ value.

The average of the absolute deviations of the the values of $\langle\rho\rangle_s$ i.e, the average of $|\delta\langle\rho\rangle|$ for various scans is shown in Table (4.11)and graphically represented in Fig.(4.14). Also appearing are the relative errors, $\frac{\Delta\langle\rho\rangle}{\langle\rho\rangle}$, which are plotted against ρ in Fig.(4.14). The quantity ρ is computed by the following equation.

$$\Delta\langle\rho\rangle = \sum_{i=1}^{n} |\delta_i\langle\rho\rangle| / n$$

where n is the total number of scans considered. Since the error band of $\langle\rho\rangle_s$ values remain fairly constant for all density runs, a decrease in the relative error with decreasing density is observed.

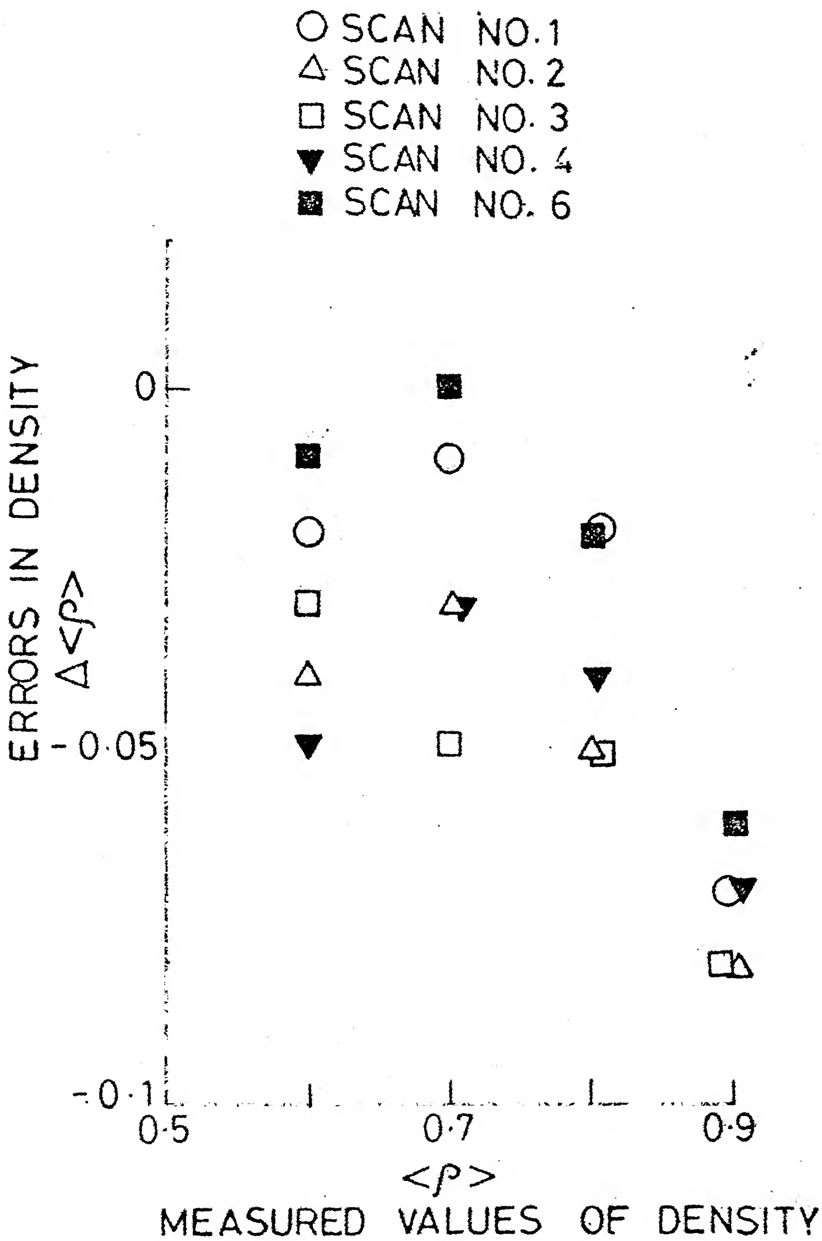


FIG. 4·13 ERROR IN DENSITY MEASUREMENTS FOR GENERALISED FILTER NO. 4

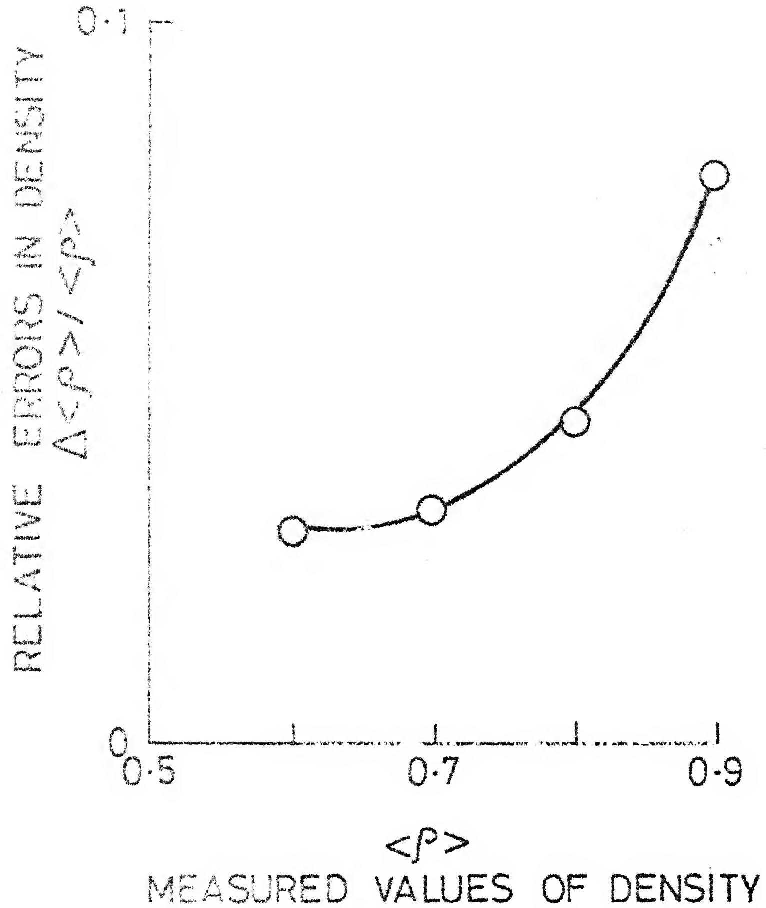


FIG. 4·14 RELATIVE ERROR IN DENSITY MEASUREMENTS FOR GENERALISED FILTER NO. 4

CHAPTER-5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions:

The following conclusions have been drawn based upon the results of the present study.

Meaningful results have been obtained using the techniques of computerised axial tomography (CAT) for density measurement in bubbly air-water flow. For cases investigated in the range $0.6 \leq \rho \leq 1.0$, the uncertainity band in the measured values of average density is found to be -0.03 , with respect to density determined experimently by direct measurement. The density is underestimated for all scans. The dotted line in Fig(4.9 to 4.12) $\langle \rho \rangle = 1.07 \langle \rho \rangle_S$ clearly shows that the error can be overcome by a general approximation. This is true for all Generalised filters.

The results of density (scan) values using Shepp and Logan filter and Parabolic filter are enclosed to give a proper insight into the problem. The improvement the generalised filter offers can be high lighted by viewing Figures (4.1) to (4.12).

The above method is approximate and its limitations can be exposed by using less number of scans(N) and less number of rays per view (LITM). Proper care should be taken while choosing N and (LITM. The values of N=20 and LITM = 40 was used for the present study.

The method ('New Algorithm'.) is accurate and exact but takes longer time to evaluate. The method also removes the necessity of rotating the source provided the distribution is centrally or radially symmetric. However repeated scans at different scan angles will be required if the flow under investigation happen to be radially assymetric.

5.2 Recommendation:

1. The Generalised filter used needs further investigation and selection of various values for Pand Zeta. The mathematics part of Generalised filter needs proper understanding.

2. The Noise error analysis as suggested by Kwoh et al (7) is to be considered and this is an important factor.

3. Plexi glass was used in the set up for data calculation but its effect was neglected i.e., not taken into

account in the algorithm. Suitable modification in the algorithm is necessiated and 'New Algorithm' comes into prominence for this problem.

4. The 'New Algorithm' explained in section 6.0 has to be adapted for experimental data by suitable modifications.

CHAPTER - 6

A NEW ALGORITHM

The Algorithm described and used in the present study is based on convolution i.e., filtered back projection. It is used primarily because of the high processing speed and reasonable engineering accuracy.

A " New Algorithm " is being proposed for the reconstruction studies in the two-phase flow area. To test the concept we generated data from a known density distribution, then used the general data to reconstruct the assumed density distribution. A brief summary of the procedure is given below:

Step 1 :- Data is represented as an array and given as a column of n elements where, each element is the chordal averaged value at different scan angles.

$$d = \begin{pmatrix} d_1 \\ d_2 \\ \cdot \\ \cdot \\ d_n \end{pmatrix}$$

We note that N or LITN explained before and defind as Number of scans is unnecessary in this case.

Step 2 :- We assume a function g, a polynomial of degree $\leq n$ in r^2.

where $g = x_1 + x_2 \, r^2 + \ldots + x_m \, r^{2m-2}$

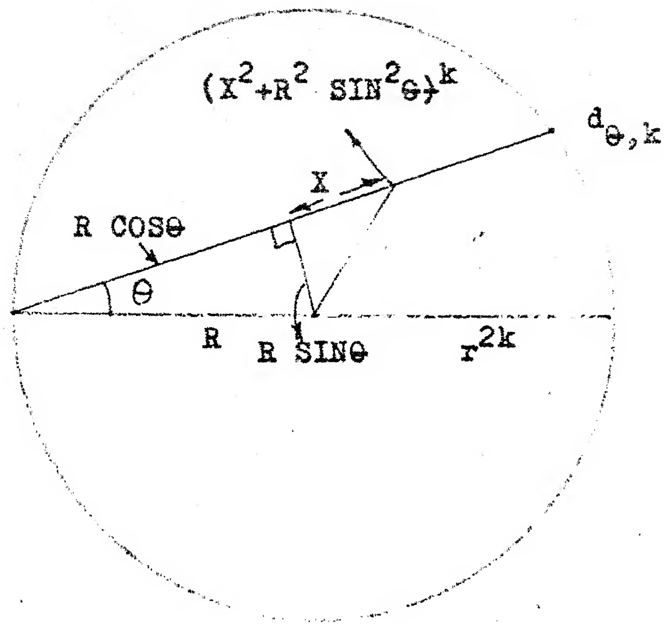


Fig. 6.1 Assumed distribution for New Algorithm.

where x is the coefficients of powers of r^2.

x can be represented as

$$\mathbf{x} = \begin{pmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ x_m \end{pmatrix}$$

Step 3 :- Now $JX = D$ (6.3)

where J is the weight of each part which when multiplied by x will give rise to d.

where

$$J_k^{(i)} = \frac{2R^2 \cos\theta_i}{2k-1} \left[R^{2k-3} + (k-1) \sin\theta_i \tan\theta_i J_{k-1}^{(i)} \right]$$

k= 2(1) m
i= 1(1) n

$J_1^{(i)} = 2R \cos\theta_i$, i^{th} element of 1st column

i = 1(1) n, This gives n x m dimension for J.

for derivation of J see Appendix E.

On solving the system of linear equations $J x = D$, we obtain the X-vector

Step 4:- The reconstructed value at the point r is given by

$$F(r) = \rho^T X = \sum_{i=0}^{m} r^{2i} x_i$$

where $$\rho = \begin{pmatrix} 1 \\ r^2 \\ \vdots \\ r^{2m-2} \end{pmatrix}$$

Step 5 :- The data used is generated especially to verify the 'New Algorithm'. The data element d is the chordal average and is calculated using the formule $d = 2 \int_0^{\cos\theta} f(r)\, dx$.

where $f(r) = f\left(\sqrt{x^2 + \sin^2\theta}\right)$ (from figure 6.1)

The accompanying data provide ample proof for the success of the elgorithm.

A FORTRAN program has also been written and employed to give the best of results. NAG library routine has been used to perform Numerical Integration in calculating data and for solving system of linear equation to find X by Eqn (6.3).

Several functions of f(r) were used to test the algorithm. Some typical cases are:

$$f(r) = \begin{cases} 1 \\ r \\ \exp(r) \\ \exp(-r) \end{cases}$$

Tables 6.1 to 6.4 show the reconstructed values, F(r), and the exact values of the various function in the interval $0.0 \leqslant x \leqslant 1.0$ in steps of 0.1.

We observe that the new algorithm predicts the unknown fuction very accurately if it is radially symmetric. This algorithm has to be modified (a different J-Matrix has to be used) for use in radiation attenuation methods. Also, the algorithm can be extended for sitation when the fuction is not radially symmetric. Such a case will involve multiple projections as currently being practised in CT algorithms.

TABLE 6.1

$f(r) = 1.0$

Sl No.	f(r)	F(r)	d
1	1.000	1.000	2.000
2	1.000	1.000	1.978
3	1.000	0.999	1.912
4	1.000	0.999	1.805
5	1.000	1.000	1.658
6	1.000	1.000	1.475
7	1.000	1.000	1.259
8	1.000	1.000	1.015
9	1.000	0.999	0.749
10	1.000	1.000	0.467
11	1.000	0.999	0.174

TABLE 6.2

$f(r) = r$

Sl No.	f(r)	F(r)	d
1	0.000	0.095	1.000
2	0.100	0.119	1.045
3	0.200	0.186	1.118
4	0.300	0.284	1.178
5	0.400	0.398	1.200
6	0.500	0.508	1.170
7	0.600	0.605	1.076
8	0.700	0.695	0.923
9	0.800	0.798	0.713
10	0.900	0.905	0.458
11	1.000	1.017	0.174

TABLE 6.3

$f(r) = \exp(r)$

Sl No.	f(r)	F(r)	d
1	1.000	1.095	3.436
2	1.105	1.124	3.473
3	1.221	1.207	3.518
4	1.345	1.334	3.522
5	1.491	1.489	3.450
6	1.649	1.657	3.273
7	1.822	1.827	2.967
8	2.014	2.008	2.521
9	2.226	2.224	1.941
10	2.460	2.465	1.246
11	2.718	2.735	0.473

TABLE 6.4

$f(r) = \exp(-r)$

Sl No.	f(r)	F(r)	d
1	1.000	0.967	1.264
2	0.905	0.915	1.205
3	0.819	0.816	1.091
4	0.741	0.739	0.944
5	0.670	0.673	0.811
6	0.607	0.605	0.671
7	0.549	0.549	0.536
8	0.497	0.497	0.409
9	0.449	0.449	0.289
10	0.406	0.406	0.175
11	0.368	0.368	0.064

```
C     This program outputs data to the tomography system it accepts
C     fan beam data for parallel to convert which converts the data
C     to parallel beam.
      INTEGER M,LITN
      REAL ALPHA,D,LAMMAX,DELLAM,T,BETA,H,LAMBDA,THETA
C     D is the distance from source to center of object
      D=4.0148734
C     T is the diameter of the object
      T=6.5
C     LITN is the number of projections in scan(fan beam)
      LITN=20
C     M is the number of rays per view(fan beam)
      M=20
C     Calculates maximum lambda
      LAMMAX=T/(2.0*SQRT(1.0-(T/(2.0*D))**2))
C     Calculates ray spacing in terms of lambda
      DELLAM=2.0*LAMMAX/FLOAT(M)
C     Calculates angular spacing between views
      ALPHA=3.1415927/FLOAT(ABS(LITN))
C     writing the output in file named input.dat
200    OPEN(UNIT=21,FILE='INPUT',ACCESS='SEQOUT')
      WRITE(21,*)D,T
      WRITE(21,*) LAMMAX,DELLAM,ALPHA
      WRITE(21,*) M,LITN
      CLOSE(UNIT=21)
      TYPE 300
300    FORMAT('  NEXT PROGRAM IS CONVERT')
      STOP
      END
```

```
C     This program converts fan beam data into parallel beam
C     data. the data are then passed to the filter function
C     Program (which is geometry dependent)
      INTEGER M,LITN,LITM,N,K,J,S,I
      REAL ALPHA,D,LAMMAX,LITA,DELLAM,LITH(41,41),T
      REAL LITP(41,41),BETA,LAMBDA,LITL,THETA, GAMMA
      OPEN (UNIT=21,FILE='INPUT.DAT',ACCESS='SEQIN')
5     FORMAT(E15.8)
C     The data is read from file input.dat created by input.for
      READ(21,*) D,T
      READ(21,*) LAMMAX,DELLAM,ALPHA
      READ(21,*) M,LITN
      CLOSE (UNIT=21)
C     N is the number of projections in scan (parallel)
      N=20
C     LITM is the number of rays per projection (parallel)
      LITM=40
C     FN gives the option to specify the required data file on
C     The tty up to 5 letters maximum,e.g. water,wanut,etc.,
      READ(5,9) FN
9     FORMAT(2A5)
      DO 10 J=1,LITN+1
      OPEN (UNIT=53,ACCESS='SEQIN',FILE=FN)
      READ(53,5) (LITH(I,J),I=1,M+1)
      CLOSE (UNIT=53)
10    CONTINUE
C     LITH is the fan beam data as an array
      DO 100 J=1,LITN+1
C     The next three statements change LITH to density values
      DO 100 I=1,LITN+1
      LITH(I,J)=1.0-LITH(I,J)
100    CONTINUE
C     LITA is the distance between parallel rays in each view
      LITA=T/FLOAT(LITM)
C     CONVERT TO PARALLEL
      DO 80 K=1,LITM+1
      LITL=LITA*FLOAT(K-1)-(T/2.)
      GAMMA=ASIN(LITL/D)
      LAMBDA=D*(SIN(GAMMA)/COS(GAMMA))
      S=1+M/2+IFIX(FLOOR(LAMBDA/DELLAM))
      IF (S.EQ.0) S=1
      DO 70 J=1,N+1
      THETA=(3.1415927/FLOAT(N))*FLOAT(J-1)
      BETA=THETA+GAMMA
      IF (BETA.LT.0.0) BETA=BETA+3.1415927
      IF (BETA.GE.3.1415927) BETA=BETA-3.1415927
      I=IFIX (FLOOR(BETA/ALPHA))+1
C     LITP is the parallel beam data as an array
      LITP(K,J)=LITH(S,I)
C     Interpolation is being done in the next few statements
      IF (S.LE.M) LITP(K,J)=LITP(K,J)+(LAMBDA/DELLAM-
     1 FLOOR(LAMBDA/DELLAM))*(LITH(S+1,I)-LITH(S,I))
      IF (I.LE.LITN) LITP(K,J)=LITP(K,J)+(BETA/ALPHA-FLOOR
     1        (BETA/ALPHA))*(LITH(S,I+1)-LITH(S,I))
70    CONTINUE
80    CONTINUE
```

```
c         Write geometry information in file named geom.dat
          OPEN (UNIT=23,FILE='GEOM',ACCESS='SEQOUT')
          WRITE (23,6) N,LITM
          WRITE (23,4) LITA
4         FORMAT(F15.9)
          CLOSE (UNIT=23)
c         Write parallel data in file named convrt.dat
          OPEN (UNIT=24,FILE='CONVRT',ACCESS='SEQOUT')
          WRITE (24,6) N,LITM
6         FORMAT(I2,3X,I2)
          WRITE(24,7) ((LITP(J,I),J=1,LITM+1),I=1,N+1)
7         FORMAT(4(E15.8,3X))
          CLOSE (UNIT=24)
          TYPE 410
410       FORMAT ('-NEXT PROGRAM IS FILTER')
          STOP
          END
c         This function computes the greatest integer less than or
c         equal to the argument. it returns a real result.
          FUNCTION FLOOR(X)
          REAL X
          FLOOR=IFIX(X)
          IF (FLOOR.GT.X) FLOOR=FLOOR-1.0
          RETURN
          END
```

```
      REAL LITP(41,41),LITW(41),SUM,LITC(41,41)
      INTEGER LITM,N,J,K,L
10    FORMAT(I2,2X,I2)
c     Read parallel data from convrt.dat created by convrt.for
      OPEN (UNIT=24,FILE='CONVRT',ACCESS='SEQIN')
      READ (24,*) N,LITM
3     FORMAT(I2,3X,I2)
      READ (24,*) ((LITP(K,J),K=1,LITM+1),J=1,N+1)
5     FORMAT(4(E15.3,3X))
      CLOSE (UNIT=24)
c     Read fourier filter from filter.dat created by filter.for
      OPEN (UNIT=51,FILE='FILTER',ACCESS='SEQIN')
c     LITW is the filter function data
      DO 30 K=1,LITM+1
      READ (51,*) LITW(K)
40    FORMAT(E15.8)
20    FORMAT(4E15.8)
30    CONTINUE
      CLOSE (UNIT=51)
c     Compute convolution
      DO 70 L=1,LITM+1
      DO 60 J=1,N+1
      SUM=0.0
      DO 50 K=1,LITM+1
      SUM=SUM+LITP(K,J)*LITW(ABS(L-K)+1)
50    CONTINUE
      LITC(L,J)=SUM
60    CONTINUE
70    CONTINUE
c     Write convoluted data in convlv.dat
      OPEN (UNIT=52,FILE='CONVLV',ACCESS='SEQOUT')
c     Writing the convoluted data
      WRITE(52,*) N,LITM
      DO 100 K=1,N+1
      WRITE(52,*) (LITC(L,K),L=1,LITM+1)
100    CONTINUE
      CLOSE (UNIT=52)
      TYPE 200
200    FORMAT('-NEXT PROGRAM IS "SUPERIMPOSITION".')
      STOP
      END
```

```
      REAL TRUET,LITF(41,41),LITC(41,41),SUM,T,THETA
      INTEGER J,L,X,Y,LITM,N
c     Read in convoluted data from convlv.dat created by convlv.for
      OPEN (UNIT=54,FILE='CONVLV',ACCESS='SEQIN')
      READ (54,*) N,LITM
 2    FORMAT(I2,2X,I2)
c     LITC is the convoluted data
      DO 6 L=1,N+1
      READ (54,*) (LITC(J,L),J=1,LITM+1)
 4    FORMAT(4E15.8)
 6    CONTINUE
      CLOSE (UNIT=54)
c     Calculate superimposition of data
      DO 30 X=1,LITM+1
      DO 20 Y=1,LITM+1
      SUM=0.0
      DO 10 J=1,N
      THETA=(3.1415927)*FLOAT(J-1)/FLOAT(N)
      TRUET=FLOAT(X-LITM/2-1)*COS (THETA)+FLOAT(Y-LITM/2-1)
     1*SIN(THETA)
      T=TRUET+FLOAT(LITM/2+1)
      L=IFIX(FLOOR(T))
      SUM=SUM+(FLOOR(T+1.0)-T)*LITC(L,J)+(T-FLOOR(T))*LITC(L+1,J)
 10   CONTINUE
c     LITF is the back-projected data as an array
      LITF(X,Y)=SUM/FLOAT(2*N)
 20   CONTINUE
 30   CONTINUE
c     Write output data in supimp.dat
      LITM=LITM+1
      OPEN (UNIT=55,FILE='SUPIMP',ACCESS='SEQOUT')
      WRITE (55,2) LITM,LITM
      WRITE(55,1) ((LITF(X,Y),X=1,LITM),Y=1,LITM)
 1    FORMAT(4E15.8)
      CLOSE (UNIT=55)
      TYPE 1000
 1000  FORMAT('-NEXT PROGRAM IS "PRINT"!')
      STOP
      END
      FUNCTION FLOOR(A)
c     Function is similar to the one explained before in convrt.for
      REAL A
      FLOOR=IFIX(A)
      IF (FLOOR.GT.A) FLOOR=FLOOR-1.0
      RETURN
      END
```

```
      LOGICAL EVEN
      REAL LITF(41,41)
      INTEGER M,LINE(41),XMAX,YMAX,SUPERI,PRINT,PRT,TITLE(20)
C     Read data from supimp.dat created by supimp.for
      OPEN(UNIT=55,FILE='SUPIMP',ACCESS='SEQIN')
      READ (55,3) XMAX,YMAX
      READ(55,1) ((LITF(I,J),I=1,XMAX),J=1,YMAX)
1     FORMAT(4E15.8,2X)
3     FORMAT(I2,2X,I2)
      CLOSE (UNIT=55)
C     Print data
      Y=9999.0
      Z=-9999.0
      DO 30 L=1,XMAX
      DO 20 J=1,YMAX
      IF(Y.GT.LITF(L,J)) Y=LITF(L,J)
      IF(Z.LT.LITF(L,J)) Z=LITF(L,J)
20    CONTINUE
30    CONTINUE
      TYPE 35
35    FORMAT('-NEGATIVE OF IMAGE(0=NO,1=YES)')
      ACCEPT *,ANS
      TYPE 36
36    FORMAT('PRINT IMAGE ON TERMINAL?(0=NO,1=YES)')
      ACCEPT *,PRT
C     Open print file
      EVEN=.FALSE.
      OPEN (UNIT=56,FILE='RESULT',ACCESS='SEQOUT')
      DO 55 L=1,XMAX
      DO 40 J=1,YMAX
      LINE(J)=IFIX(0.5+99.0*(LITF(L,J)-Y)/(Z-Y))
      IF(ANS.NE.1) LINE(J)=99-LINE(J)
40    CONTINUE
      WRITE (56,45) (LINE(M),M=1,YMAX)
45    FORMAT(1H ,50I2)
      IF (EVEN) GOTO 300
      WRITE(56,200) (LINE(M),M=1,YMAX,2)
      WRITE(56,200) (LINE(M),M=1,YMAX,2)
200    FORMAT(1H+,25(I2,2X))
      GOTO 500
300    WRITE(56,400) (LINE(M),M=2,YMAX,2)
      WRITE(56,400) (LINE(M),M=2,YMAX,2)
400    FORMAT(1H+,25(2X,I2))
500    EVEN=.NOT.EVEN
      IF (PRT.EQ.1) TYPE 45, (LINE(M),M=1,YMAX)
55    CONTINUE
      WRITE(56,60) Y,Z
60    FORMAT(/' MINIMUM LITF=',E15.8,' MAXIMUM LITF=',E15.8)
      IF (PRT.EQ.1) TYPE 60 ,Y,Z
70    FORMAT(/'-LITF=',E15.8)
          CLOSE (UNIT=56)
      STOP
      END
```

```
c     This program integrates the litf values printed out in
c     Result.dat and gives a number for the 31x31 values.
c     The number can be changed by using a higher value for the matri
      PARAMETER NN=41
      INTEGER ST(41),A(41,41),B(41,41)
c     Input is taken from result.dat created by print2.for
      OPEN (UNIT=21,FILE='RESULT',ACCESS='SEQIN')
      READ(21,*) ((B(I,J),J=1,NN),I=1,NN)
      SUM=0.0
      NUM=0
      DO 10 I=5,35
      DO 20 J=5,35
      NUM=NUM+1
20    SUM=SUM+B(I,J)
10    CONTINUE
      AVRAGE=SUM/NUM
c     The output is created in answer.dat
      OPEN(UNIT=23,FILE='ANSWER',ACCESS='SEQOUT')
c     Open (unit=23,device='tty',access='seqout')
      WRITE(23,*) AVRAGE,SUM,NUM
      STOP
      END
```

```
c     This program calculates the fourier filter function. this
c     particular function is the parabolic filter finction
      REAL LITA,CONST,W(41)
      INTEGER LITM,N,K,GEOM,FILTER
c     Read geometry factors
      OPEN (UNIT=23,FILE='GEOM',ACCESS='SEQIN')
      READ (23,*)N,LITM
20    FORMAT(I2,3X,I2)
      READ (23,*) LITA
10    FORMAT(E15.8)
      CLOSE(UNIT=23)
c     Calculates constant
      W(1)=(3.1415927)/(3.*LITA*LITA)
      CONST=-1.0/(3.1415927*LITA*LITA)
c     Write filter values
      OPEN (UNIT=51,FILE='FILTER',ACCESS='SEQOUT')
      DO 30 L=1,LITM+1
      W(L+1)=CONST/FLOAT((L)**2)
30    CONTINUE
      WRITE (51,10) (W(L),L=1,41)
      CLOSE (UNIT=51)
      STOP
      END
```

```
C     These are filter values for Generalised Filter for Odd N's
C     The values of Zeta and P are specified in the Program
C     The Subroutine used is the NAG library routine D01AKF
C     The routine is called twice for the two seperate terms.
      INTEGER IW(600)
      DIMENSION W(2000),RESULT(42),VALUE(42),FINAL(42)
      EXTERNAL F3,F4
      COMMON N,P,ZETA,PIE
      A=0.0
      PIE=22./7.
      B=2.*PIE
      EPSABS=0.1E-01
      EPSREL=0.1E-01
      IFAIL=0
      ZETA=4.75E-03
      P=2.0
      DO 10 N=3,41,2
C     The routine below does the first part of integration
C     this uses a function called f3 which is external
      CALL D01AKF(F3,A,B,EPSABS,EPSREL,RESULT(N),ABSERR,
     1   W,2000,IW,600,IFAIL)
10    CONTINUE
      DO 11 N=3,41,2
C     The routine below does the second part of integration
C     this uses a function called f4 which is external
      CALL D01AKF(F4,A,PIE,EPSABS,EPSREL,VALUE(N),ABSERR,
     1   W,2000,IW,600,IFAIL)
2     FORMAT(E15.6)
      FINAL(N)=RESULT(N)+VALUE(N)
11    FINAL(N)=FINAL(N)/(PIE*0.1625*0.1625*N*N)
      WRITE(24,2) (FINAL(I),I=3,42,2)
      WRITE(5,*) IFAIL,ABSERR,A,B
      STOP
      END
      FUNCTION F3(X)
C            This is used for the first part of integration
      COMMON N,P,ZETA,PIE
      SUM1=0.0
      AS=0.1625
      K=(N-3)/2
      DO 100 J=1,K
      Y=X+2.*PIE*FLOAT(J)
      Y1=(Y/(AS*FLOAT(N)))**P
100    SUM1=SUM1+Y*EXP(-ZETA*Y1)
      F3=SUM1*COS(X)
      RETURN
      END
      FUNCTION F4(X)
C     This is used for the second part of integration
      COMMON N,P,ZETA,PIE
      SUM2=0.0
      AS=0.1625
      YY=X+PIE*(FLOAT(N)-1.)
      YY1=(YY/(AS*N))**P
      SUM2=COS(X)*YY*EXP(-ZETA*YY1)
      F4=SUM2
      RETURN
      END
```

```
C     The filter values are the Generalised Filter for Even N's
C     The values of Zeta and P are specified in the Program
C     The Subroutine used is the NAG library routine D01AKF
      INTEGER IW(600)
      DIMENSION W(2000),RESULT(42)
      EXTERNAL F2
      COMMON N,P,ZETA,PIE
      A=0.0
C     A is the lower limit and B is the upper limit of the integral
      PIE=22./7.
      B=2*PIE
C     EPSABS and EPSREL are the absolute and relative errors.
      EPSABS=0.1E-01
      EPSREL=0.1E-01
      IFAIL=0
      ZETA=4.75E-03
C     Zeta is the damping coefficient
      P=2.0
      DO 10 N=2,40,2
      CALL D01AKF(F2,A,B,EPSABS,EPSREL,RESULT(N),ABSERR,
     1   W,2000,IW,600,IFAIL)
      RESULT(N)=RESULT(N)/(PIE*0.1625*0.1625*N*N)
10    CONTINUE
      WRITE(24,2) (RESULT(I),I=2,40,2)
C     Result has the value of the integral
2     FORMAT(E15.6)
      STOP
      END
      FUNCTION F2(X)
C     These statements are the value of the integral
C     employed in this Program,w.r.t. x
      COMMON N,P,ZETA,PIE
      SUM=0.0
      AS=0.1625
      K=N/2-1
      ZN=N
      DO 100 J=1,K
      Y=X+2.*PIE*FLOAT(J)
      Y1=(Y/(AS*ZN))**P
100    SUM=SUM+(Y*EXP(-ZETA*Y1))
      F2=SUM*COS(X)
      RETURN
      END
```

```
C     These are the filter values of Generalised Filter for N=0
C     The values of Zeta and P are specified in the Program.
      INTEGER IW(200)
      REAL W(800)
      EXTERNAL F0
      A=0.0
      B=22./(7.*0.1625)
      EPSABS=0.1
      EPSREL=0.1
      IFAIL=0
      CALL D01AKF(F0,A,B,EPSABS,EPSREL,RESULT,ABSERR,
     1  W,800,IW,200,IFAIL)
      RESULT=RESULT*7./22.
      WRITE(5,*) RESULT,ABSERR,A,B,IFAIL
      STOP
      END
      FUNCTION F0(X)
C     These statements calculate the value of the integral
C     function used in the program,w.r.t. x
      ZETA=4.75E-03
      P=2.0
      F0=X*EXP((-(ZETA)*X**P))
      RETURN
      END
```

```
C     These are the values of generalised filter for n=1
C     the values of zeta and p are specified in the program
C     the Subroutine used is the nag library routine d01akf
      INTEGER IW(600)
      REAL W(2000)
      EXTERNAL F1
      A=0.0
      B=22./7.
      EPSABS=0.1E-04
      EPSREL=0.1E-02
      IFAIL=0
      CALL D01AKF(F1,A,B,EPSABS,EPSREL,RESULT,ABSERR,
     1   W,2000,IW,600,IFAIL)
      RESULT=RESULT/(B*0.1625*0.1625)
      WRITE(5,*) RESULT,ABSERR,A,B,IFAIL
      STOP
      END
      FUNCTION F1(X)
C     These statements calculate the value of the integral
C     function used and says thatt is w.r.t. x
      ZETA=4.75E-03
      P=2.0
      F1=X*COS(X)*EXP(-ZETA*(X/0.1625)**P)
      RETURN
      END
```

```
C     These Program reads the values of Generalised filter's
C     Odd and Even and puts them in a single file inserting
C     alternate lines from the two inputs.The output is available
C     in For51.dat and input through Odd.dat and Even.dat
      OPEN(UNIT=21,ACCESS='SEQIN',FILE='EVEN')
      OPEN(UNIT=22,ACCESS='SEQIN',FILE='ODD')
10    READ (21,*,END=20) A
      WRITE (51,*) A
      READ (22,*,END=20) A
      WRITE (51,*) A
      GOTO 10
20    STOP
      END
```

Table B.7 Scan No. 1 - Normalized

DEGREES

TYPE SCAN	-30	-27.5	-25	-22.5	-20	-17.5	-15	-12.5	-10	-7.5	-5	-2.5	0	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5
AIR	1.191	.740	.757	.881	.931	.955	.976	.979	.994	1.001	1.004	1.003	1.000	.997	.999	.992	.980	.969	.956	.928	.877	.788	.561	1.172
46% VOID	1.195	.766	.466	.435	.416	.396	.389	.388	.393	.401	.406	.405	.409	.408	.405	.406	.401	.382	.398	.405	.415	.448	.539	1.170
40% VOID	1.167	.761	.454	.408	.370	.358	.342	.335	.331	.339	.341	.340	.337	.340	.348	.339	.345	.337	.349	.360	.382	.424	.519	1.172
30% VOID	1.185	.739	.464	.356	.301	.267	.244	.235	.227	.218	.220	.216	.222	.223	.224	.234	.241	.244	.262	.286	.321	.386	.507	1.172
20% VOID	1.189	.747	.425	.331	.267	.220	.190	.176	.156	.151	.147	.146	.145	.148	.156	.158	.172	.189	.215	.256	.292	.364	.498	1.166
10% VOID	1.197	.725	.428	.318	.242	.191	.148	.122	.097	.086	.081	.076	.086	.086	.091	.102	.119	.140	.168	.217	.267	.353	.499	1.153
WATER	1.200	.740	.422	.294	.205	.143	.097	.066	.040	.023	.010	.004	.000	.003	.014	.028	.048	.077	.118	.170	.231	.346	.517	1.181
WALNUT (ρ=.732)	1.184	.751	.561	.462	.397	.365	.333	.294	.261	.234	.224	.213	.216	.206	.209	.219	.236	.261	.303	.350	.402	.492	.540	1.179
PINE (ρ=.41)	1.185	.739	.578	.628	.593	.567	.540	.525	.503	.490	.482	.481	.478	.478	.487	.493	.506	.520	.546	.565	.583	.625	.543	1.172

Table B.8 Scan No: 2 - Normalized

DEGREES

TYPE SCAN	-30	-27.5	-25	-22.5	-20	-17.5	-15	-12.5	-10	-7.5	-5	-2.5	0	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30
AIR													2574												2378
40% VOID	1.179	0.754	0.447	0.404	0.374	0.340	0.335	0.334	0.335	0.330	0.347	0.347	0.351	0.353	0.352	0.346	0.350	0.347	0.351	0.359	0.377	0.426	0.549	1.166	1.169
30% VOID	1.186	0.742	0.439	0.364	0.315	0.286	0.258	0.250	0.241	0.239	0.240	0.238	0.242	0.245	0.246	0.250	0.262	0.274	0.288	0.315	0.335	0.399	0.542	1.158	1.167
20% VOID	1.182	0.735	0.435	0.346	0.284	0.242	0.208	0.192	0.173	0.165	0.162	0.160	0.161	0.165	0.165	0.181	0.188	0.206	0.235	0.268	0.309	0.387	0.541	1.168	1.169
10% VOID	1.179	-.735	0.430	0.326	0.247	0.198	0.159	0.131	0.112	0.090	0.088	0.089	0.090	0.095	0.102	0.117	0.125	0.150	0.190	0.230	0.278	0.377	0.535	1.169	1.170
WATER													746												

Table B.9 Scan No. 3 - Normalized

DEGREES

TYPE SCAN	-30	-27.5	-25	-22.5	-20	-17.5	-15	-12.5	-10	-7.5	-5	-2.5	0	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30
AIR													2605											2917	
40% VOID	1.184	0.756	0.452	0.405	0.368	0.348	0.334	0.330	0.338	0.336	0.345	0.346	0.360	0.352	0.359	0.357	0.346	0.352	0.363	0.369	0.385	0.427	0.545	1.18	1.18
30% VOID	1.195	0.765	0.448	0.371	0.334	0.296	0.282	0.268	0.263	0.257	0.267	0.268	0.265	0.264	0.270	0.279	0.279	0.283	0.296	0.323	0.338	.402	0.536	1.166	1.167
20% VOID	1.184	0.736	0.427	0.335	0.266	0.229	0.202	0.181	0.168	0.158	0.156	0.163	0.170	0.168	0.172	0.176	0.198	0.211	0.231	0.260	0.308	0.389	0.541	1.171	1.167
10% VOID	1.187	0.737	0.423	0.314	0.239	0.188	0.149	0.124	0.100	0.097	0.088	0.084	0.086	0.087	0.104	0.114	0.123	0.152	0.181	0.221	0.280	0.375	0.532	1.169	1.169
WATER													763												
WALNUT (ρ=.732)																									
PINE (ρ=.41)																									

Table B.10 Scan No. 4 - Normalized

DEGREES

TYPE SCAN	-30	-27.5	-25	-22.5	-20	-17.5	-15	-12.5	-10	-7.5	-5	-2.5	0	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30
AIR													2575												2893
40% VOID	1.182	0.757	0.454	0.414	0.382	0.372	0.361	0.356	0.361	0.371	0.365	0.370	0.370	0.379	0.366	0.370	0.365	0.368	0.369	0.367	0.383	0.426	0.539	1.167	1.163
30% VOID	1.179	0.730	0.437	0.367	0.310	0.291	0.261	0.251	0.250	0.245	0.246	0.248	0.253	0.252	0.26	0.253	0.269	0.274	0.283	0.307	0.343	0.406	0.513	1.161	1.163
20% VOID	1.176	0.733	0.430	0.331	0.267	0.231	0.196	0.171	0.160	1.16	0.152	0.154	0.156	0.159	0.165	0.167	0.180	0.205	0.232	0.262	0.305	0.339	0.53	1.16	1.16
10% VOID	1.176	0.730	0.423	0.305	0.237	0.183	0.142	0.118	0.097	0.085	0.078	0.077	0.073	0.080	0.080	0.098	0.117	0.145	0.176	0.221	0.273	0.370	0.538	1.163	1.164
WATER													739												
WALNUT (ρ=.732)																									
PINE (ρ=.41)																									

Table B.11 Scan No. 5 - Normalized

DEGREES

TYPE SCAN	-30	-27.5	-25	-22.5	-20	-17.5	-15	-12.5	-10	-7.5	-5	-2.5	0	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30
AIR													2565												2870
40% VOID	1.186	0.760	0.453	0.414	0.382	0.363	0.343	0.344	0.347	0.348	0.353	0.353	0.367	0.363	0.362	0.365	0.360	0.359	0.364	0.379	0.394	0.440	0.549	1.177	1.185
30% VOID	1.185	0.753	0.452	0.392	0.337	0.309	0.279	0.274	0.262	0.266	0.267	0.270	0.272	0.266	0.269	0.273	0.283	0.292	0.302	0.330	0.355	0.423	0.549	1.179	1.180
20% VOID	1.190	0.753	0.448	0.388	0.327	0.286	0.261	0.241	0.226	0.218	0.213	0.213	0.217	0.213	0.213	0.223	0.237	0.247	0.261	0.292	0.335	0.414	0.542	1.165	1.166
10% VOID	1.186	0.763	0.453	0.380	0.316	0.261	0.233	0.202	0.186	0.166	0.158	0.154	0.157	0.155	0.16[illegible]	0.177	0.196	0.210	0.246	0.285	0.338	0.424	0.541	1.173	1.169
WATER													750												

Table B.12 Scan No. 6 - Normalized

DEGREES

TYPE SCAN	-30	-27.5	-25	-22.5	-20	-17.5	-15	-12.5	-10	-7.5	-5	-2.5	0	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30
AIR													2575												2900
40% VOID	1.177	.751	.444	0.407	0.368	0.348	0.328	0.327	0.32	0.321	0.331	0.333	0.335	0.336	0.341	0.338	0.336	0.336	0.354	0.359	0.386	0.425	0.540	1.176	1.171
30% VOID	1.188	0.75	0.441	0.360	0.307	0.263	0.240	0.229	0.223	0.213	0.210	0.211	0.212	0.217	0.218	0.226	0.229	0.253	0.262	0.292	0.327	0.394	0.534	1.16	1.165
20% VOID	1.184	0.733	0.427	0.329	0.258	0.220	0.182	0.161	0.147	0.138	0.131	0.133	0.136	0.132	0.140	0.152	0.169	0.192	0.220	0.249	0.291	0.382	0.534	1.165	1.169
10% VOID	1.182	0.74	0.42	0.302	0.227	0.176	0.138	0.115	0.088	0.081	0.017	0.070	0.070	0.074	0.082	0.094	0.117	0.139	0.177	0.213	0.275	0.366	0.534	1.17	1.167
WATER													757												

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756169797235292622191614121110 9 8 8 8 8 8 8 8 9 910121315171923283542477486715 9
69697179432926221916131210 9 8 7 7 6 6 6 6 6 6 7 8 9 91113141619232936493528975 64
7665805730282319161311 10 9 8 7 6 5 5 5 5 5 5 5 5 6 6 7 8 911131417202431394565 8866
7072773529242017141110 8 7 6 5 5 4 4 4 3 3 4 4 4 4 5 6 7 8 911131517212634424985 76
73805530272218141210 9 7 6 5 4 4 3 3 3 3 3 3 3 3 4 4 5 5 6 8 911131519233038456488
717939292420161311 9 8 6 5 4 4 3 3 2 2 2 2 2 2 2 3 3 4 5 5 7 81012141721263442528 9
786730282218141210 8 7 5 4 4 3 3 2 2 2 1 1 1 2 2 2 2 3 4 5 6 7 911131519233140477 7
8052302621171311 9 7 6 5 4 3 2 2 2 1 1 1 1 1 1 1 2 2 2 3 4 5 6 8101214172228374464
8242292419151210 8 7 5 4 3 3 2 2 1 1 1 1 1 1 1 1 1 2 2 3 4 5 6 7 911141620263543 56
82342923181512 9 8 6 5 4 3 2 2 1 1 0 0 0 0 1 1 1 1 1 2 2 3 4 5 7 8101316192533425 1
78322822181411 9 7 6 4 3 3 2 1 1 0 0 0 0 0 0 1 1 1 1 2 2 3 4 5 6 8101315192332 4147
75302822171411 9 7 5 4 3 2 2 1 1 0 0 0 0 0 0 1 1 1 2 2 3 4 5 6 8101215182331 4046
71302722171411 9 7 5 4 3 2 2 1 1 0 0 0 0 1 0 0 1 1 1 2 2 3 4 5 6 810121518233140 47
75302822171411 9 7 5 4 3 2 2 1 1 0 0 0 0 0 0 0 1 1 1 2 2 3 4 5 6 8101215182331 4046
78322822181411 9 8 6 4 3 3 2 1 1 0 0 0 0 0 0 1 1 1 1 2 2 3 4 5 6 8101315192432 4147
82342923191512 9 8 6 5 4 3 2 2 1 1 1 0 0 0 1 1 1 1 2 2 3 3 4 5 7 9101316192533 4251
8242292420151210 8 7 5 4 3 3 2 2 1 1 1 1 1 1 1 1 1 2 2 3 4 5 6 7 9111416202635 4356
8052302621171311 9 7 6 5 4 3 3 2 2 1 1 1 1 1 1 2 2 3 3 4 5 6 8101214172228374464
786730282218141210 8 7 5 4 4 3 3 2 2 2 1 1 1 2 2 2 2 3 4 5 6 7 911131519233140477 7
717939292420161311 9 8 6 5 4 4 3 3 2 2 2 2 2 2 2 3 3 4 5 5 7 81012141721263442528 9
73805530272218141210 9 7 6 5 4 4 3 3 3 3 3 3 3 3 4 4 5 5 6 8 911131519233038456488
7072773529252017141210 9 7 6 5 5 4 4 4 4 4 4 4 4 5 5 6 7 8 911131517212634424985 76
7666805730282319161311 10 9 8 7 6 5 5 5 5 5 5 5 5 6 6 7 8 911131417202431394565 8866
69697179433026221916131210 9 8 8 7 6 6 6 6 6 6 6 7 8 91011131417192329364935289 7564
756169797235292622191614121110 9 9 8 8 8 8 8 8 8 9 910121315171923283542477486715 9
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```

MINIMUM LITF= 0.68083083E+00 MAXIMUM LITF= 0.26152078E+01

These are the values for Calibration of Water(p=1.0) density for Shepp and Logan Filter

LITF=1.075

```
6250606356646467746977778888898683807470666768727682929999868074736862605654604652
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5652616373768785704331292624222120201920192021212223242729323340577794827160615951
6360716576858462353027232120191818181818181919202122232527313336537593637167605 5
6358687187845932292522191817171616161616161717181819202122242630333552759576696757
6564758384623228242018171616151514141414141515161517181920222326293335537693796863
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768084553027211817161514131312121111111111111111121213141517192022242732355507991 76
768675352823191716151413131211111101010  910101010111213141517192022252833376392 82
87845430252018161514131312111110 9 9 8 8 8 8 9 91011111214151719212326313449 7695
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7432272117161515131211 10 9 8 7 6 6 6 6 5 4 3 4 5 5 6 7 8 8 9101112141619212327333662
723027201716151312111 0 9 7 7 6 6 6 5 4 3 2 3 4 5 6 7 7 8 9101112141619212326323560
683026201716141312111 0 9 7 7 6 6 6 5 3 2 0 2 3 5 6 7 7 8 9101112141618212326323558
72302720171615131211 10 9 7 7 6 6 6 5 4 3 2 3 4 5 6 7 7 8 9101112141619212326323560
7532272117161513121110 9 8 7 6 6 6 6 5 4 3 4 5 6 6 7 8 8 9101112141619212327333662
79342821181615141312111 0 8 7 7 6 6 6 6 5 5 5 6 6 7 7 8 9.9101213151719212428333767
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845130241917161513121111 10 8 7 7 7 6 6 6 7 7 7 8 8 9 910111214161820222530344778
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574454585159596168647272838384807774696560616367717687939480756968625755501495541 47
```

MINIMUM LITF= 0.45956461E+00 MAXIMUM LITF= 0.20722400E+01

These are the values for Calibration of Walnut(p=0.73) density for Shepp and Logan Filter.

LITF=0.6986

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5421171311 9 7 7 6 5 4 3 3 2 2 1 0 0 0 0 0 1 1 2 2 1 1 1 2 3 3 4 5 6 8 8 911151469
5120171311 8 7 7 6 5 4 3 3 2 1 1 0 0 0 0 1 1 1 2 2 2 1 1 2 3 3 4 5 6 8 8 911151365
4920161311 9 7 7 6 5 4 3 3 2 1 1 0 0 0 0 1 1 1 1 2 2 1 1 2 3 3 4 5 6 8 8 911151360
5120171311 8 7 7 6 5 4 3 3 2 1 1 0 0 0 0 1 1 1 2 2 2 1 1 2 3 3 4 5 6 8 8 911151365
5521171311 9 7 7 6 5 4 3 3 2 2 1 0 0 0 0 1 1 1 2 2 2 1 2 2 3 4 4 5 6 8 9 911151469
6023181412 9 7 7 6 5 4 4 3 3 2 1 1 1 0 1 1 1 1 2 1 1 1 2 2 3 4 4 5 6 8 9 912151775
662818151210 8 7 7 6 5 4 3 3 2 2 1 1 1 1 1 1 1 1 1 1 1 2 2 3 4 4 5 7 8 91012152578
743619151311 8 7 7 6 5 4 4 3 3 2 2 2 1 1 1 1 1 1 1 1 2 3 3 4 5 6 7 8 91014143780
864620171311 9 7 7 6 6 5 4 3 3 3 2 2 2 1 1 1 1 1 1 1 2 3 3 4 4 5 6 8 8 91115135585
94592618141210 8 7 7 6 5 4 4 3 3 2 2 2 2 2 2 2 2 2 3 3 4 4 5 6 7 8 9101215227284
92733819161311 9 7 7 6 6 5 4 4 3 3 3 2 2 2 2 2 2 3 3 3 4 4 5 6 7 8 9 9111414418085
7391552318151210 8 7 7 6 6 5 4 4 4 3 3 3 3 3 3 3 4 4 4 5 6 7 8 8 91013151868 8370
648874392016131210 8 7 7 6 6 5 5 4 4 4 4 4 4 4 4 4 5 5 6 7 8 8 91012151443817571
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4347545975937144231816141312111010 9 9 8 8 8 8 9 9 9 91011131515185380817155634855
3949495459759374492819171514131211111010101010101011111314151426618185710651503744
3836445154596691835938231917161414131312121212131314151614184372857964555149503954
4642494449545668859474543725191817171616161616161615142242698285777160635051503749
2724403448455452576985887157433325201816161515161826385572808475695454454837403722 36
4636534446505157626270799799917871666159586468757983888586717260655654559454493653
```

MINIMUM LITF= 0.34922565E+00 MAXIMUM LITF= 0.18410774E+01

These are the values for Calibration of Pine(p=0.41) density for Shepp and Logan Filter.

LITF=0.351

```
1111271121182129314046628082654738313030334249565960564647384330362527271533171333
12183121423149405262817849312118151211 9 8 7 9122237577577665555414125351630191333
283132243130415678835020191511 8 6 5 4 4 3 3 3 3 3 3 31438697562555547513537291735
12212435415159846433201510 7 5 5 4 4 4 4 3 3 3 2 2 2 2 2 2 94072725650393434372850
2242324142678351231711 7 5 5 4 4 4 4 4 3 3 3 3 3 2 1 1 1 1 219617462525434341332
203230516786462214 9 5 5 5 4 4 4 4 5 5 5 4 4 4 4 4 3 3 2 1 1 1 1 85174575238503244
2250425983462114 8 5 5 5 4 5 5 5 5 5 5 5 5 5 5 4 4 4 4 3 3 2 1 1 1 445740149462244
29415684512214 7 5 5 4 5 5 5 6 5 5 5 5 5 5 4 4 4 4 4 4 4 3 3 2 1 0 1 4517355543842
325378642414 8 5 5 4 5 5 6 5 5 5 4 4 4 4 4 4 4 4 4 4 4 4 3 3 2 1 0 0 80071543752
4163833317 9 5 5 4 5 5 6 5 5 4 4 4 4 4 4 4 5 5 5 5 5 4 4 4 4 4 3 2 1 0 11871605246
4782512011 6 5 4 5 5 6 5 4 4 4 4 5 5 5 5 5 5 5 5 5 4 5 5 5 5 4 4 4 4 3 2 1 0 139735159
64792715 7 5 5 5 5 6 5 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 5 4 4 4 3 3 1 0 0 8666353
82512011 5 5 4 5 6 5 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 5 4 4 4 3 2 1 0 1377362
853316 7 5 5 5 6 5 5 4 5 5 5 5 5 5 5 6 5 5 5 5 5 5 4 4 4 4 4 4 4 3 2 0 0137161
692312 6 5 5 5 6 5 4 5 5 5 5 5 5 6 6 6 6 5 5 5 5 5 5 5 4 4 4 4 4 4 3 2 1 0 15371
512010 5 5 5 6 6 5 4 5 5 5 5 6 6 6 6 6 6 6 6 6 6 5 5 5 5 4 4 4 4 4 4 3 2 1 0 13274
3917 8 5 5 5 6 5 4 5 5 5 5 5 6 6 6 6 6 6 6 6 6 6 5 5 5 4 4 4 4 4 4 4 3 1 0 01775
3015 6 5 4 5 6 5 4 5 5 5 5 5 6 6 6 6 6 6 6 6 6 6 6 5 5 4 4 4 4 4 4 4 3 2 0 0 774
2714 6 5 4 5 6 5 4 5 5 5 5 6 6 6 6 6 6 6 6 6 6 6 6 5 5 5 4 4 4 4 4 4 3 2 1 0 370
2513 6 5 5 5 6 5 4 5 5 5 5 6 6 6 6 6 6 5 5 6 6 6 6 6 5 5 4 4 4 4 4 4 3 2 1 0 165
2412 6 5 5 5 6 5 4 5 5 5 5 6 6 6 6 6 6 5 5 5 6 6 6 6 5 5 4 4 4 4 4 4 3 2 1 0 159
2513 6 5 5 5 6 5 4 5 5 5 5 6 6 6 6 6 6 5 6 5 6 6 6 6 5 5 5 4 4 4 4 4 4 3 2 1 0 165
2714 6 5 5 5 6 5 4 5 5 5 5 6 6 6 6 6 6 6 6 6 6 6 5 5 5 4 4 4 4 4 4 3 2 1 0 370
3015 6 5 4 5 6 5 4 5 5 5 5 6 6 6 6 6 6 6 6 6 6 6 5 5 5 4 4 4 4 4 4 3 2 1 0 774
3917 8 5 5 5 6 5 5 5 5 5 5 5 6 6 6 6 6 6 6 6 6 5 5 5 5 4 4 4 4 4 4 4 3 1 0 01775
511910 5 5 5 5 6 5 4 5 5 5 5 5 6 6 6 6 6 6 5 5 5 5 5 4 4 4 4 4 4 4 4 3 2 1 0 13273
692312 6 5 4 5 6 5 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 4 4 4 4 4 3 2 1 0 15370
843216 7 5 4 5 5 5 5 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 4 4 4 4 3 3 1 0 0137161
82512010 5 5 4 5 6 5 4 4 4 5 5 5 5 5 5 5 5 5 5 5 4 4 4 4 4 4 4 4 3 2 1 0 1377362
64792715 7 5 5 5 5 6 5 4 4 4 5 5 5 5 5 5 5 5 5 5 4 4 4 4 5 4 4 4 3 3 1 0 0 8666353
4782512011 6 5 4 5 5 6 5 4 4 4 4 5 5 5 5 5 5 5 5 4 4 5 5 5 4 4 4 4 3 2 1 0 139735159
4163833317 9 5 5 4 5 5 6 5 5 4 4 4 4 4 4 5 5 5 5 5 5 5 4 4 4 4 3 2 1 0 11871605246
325378642415 8 5 5 4 5 5 6 5 5 5 4 4 4 4 4 4 4 5 4 4 4 4 3 3 2 1 0 0 80071543752
29415684512213 7 5 5 4 5 5 5 6 5 5 5 5 4 4 4 4 4 4 4 4 4 3 2 2 1 0 0 3517355543842
2150415983462113 7 5 5 4 4 4 5 5 5 5 5 5 5 4 4 4 4 4 4 3 3 2 1 1 0 0 345740149462143
193230516786462214 9 5 5 4 4 4 4 4 4 4 4 4 4 4 4 4 3 3 2 2 1 1 0 1 85174575238503244
2242314042668351231611 6 5 4 4 4 4 3 3 3 3 3 3 3 2 2 1 1 1 1 1 119617461525433341331
112023344050588363321914 9 6 4 4 3 3 3 3 2 2 2 2 1 1 1 1 1 83971715549383433372750
273131233129415577824925181410 7 5 4 3 3 2 2 2 2 2 2 21437687461545546503436291634
 91629183928473750597975472919151210 8 7 5 5 6 91934547274645253383922321327161130
292945283936383649576379979836455494848505966737777746465566047534344453350353150
```

MINIMUM LITF=-0.14364844E+00 MAXIMUM LITF= 0.18215783E+01

These are the values for Calibration of Air(p=0.0) density for Shepp and Logan Filter.

LITF=0.0966

```
6760597465737675817882777574808485837975706766656976879999948583767771697059685951
6051536355686373717569748384756455504746464647494949495263828981807278677358625646
5953606968797676717082816551433937353534343537384144485050516485877871636766636254
7363596970717470808366484136333231302928282829303235384247525255749082797369615947
6455687079737182785541363331292624232222222222232526293236414852516587857273687458
7268797173718373483833312825222120191818181818192021232528323845515163898580646857
7562767471836945363229252220181716151414141415151617192023263035425152628762737960
7472767082724536312824211816151313121211111112121314161719212429344251515690807365
807171807747363127232017151312111010  9  9  9  9101011121314161821242834435151748881 65
767470835438322823191714131110  9  8  8  7  7  7  7  7  8  9101112131618202429354552558783 72
80698266413329242017141211  9  8  7  7  6  6  6  6  6  5  7  8  91011131518212530384852659074
757381483531252017141210  9  8  7  6  5  5  4  4  4  4  5  5  5  6  7  8101113161822263342525284 83
7382654032282218151211  9  7  6  5  5  4  4  3  3  3  3  3  4  4  5  6  7  8101114161923293747526688
72835036302420161311  9  8  6  5  4  4  3  3  3  3  2  2  3  3  3  4  5  6  7  8101215182126324242525588
79744233282218141210  8  7  5  4  4  3  3  2  2  2  2  2  2  3  3  4  5  6  7  911131619232938505276
826239312620171311  9  7  6  5  4  3  3  2  2  1  1  1  1  1  2  2  2  3  4  5  6  810121518222735465265
845436302419151210  8  6  5  4  3  3  2  1  1  1  1  1  1  1  1  2  2  3  3  4  6  7  9111417202532435258
8448342923181412  9  8  6  5  4  3  2  1  1  1  0  0  0  1  1  1  1  2  2  3  4  5  7  8101316192431415253
8244332822181411  9  7  5  4  3  2  2  1  0  0  0  0  0  0  1  1  1  2  2  3  4  5  6  8101216192329395151
8043332821171311  9  7  5  4  3  2  1  1  0  0  0  0  0  0  1  1  1  2  2  3  3  5  6  8101215192329385150
7743332821171311  9  7  5  4  3  2  1  1  0  0  0  0  1  1  1  1  1  2  2  3  3  5  6  8101215182329385052
8043332821171311  9  7  5  4  3  2  1  1  0  0  0  0  0  0  1  1  1  2  2  3  3  5  6  8101215192329385151
8244332822181411  9  7  5  4  3  3  2  1  1  0  0  0  0  0  1  1  1  2  2  3  4  5  6  8101216192330395151
844834292318141210  8  6  5  4  3  2  1  1  1  0  0  1  1  1  1  2  2  2  3  4  5  7  8101316202431415253
845436302419151210  8  6  5  4  3  3  2  1  1  1  1  1  1  1  1  2  2  3  3  4  6  7  9111417202532435258
826239312620171311  9  7  6  5  4  3  3  2  2  1  1  1  1  1  2  2  2  3  4  5  6  810121518222735465266
79744233282218141210  8  7  5  4  4  3  3  2  2  2  2  2  2  3  3  4  5  6  7  911131619232938505276
72835036302420161311  9  8  6  5  4  4  3  3  3  3  2  2  3  3  3  4  5  6  7  81012151821263242525589
7382654032282218151211  9  7  6  5  5  4  4  3  3  3  3  3  4  4  5  6  7  8101114161923293747526688
757381483631252017141211  9  8  7  6  5  5  5  4  4  4  5  5  6  6  7  810111316182226334252538483
806982664133292420171412 11  9  8  7  7  6  6  6  6  6  6  7  8  910111315182125303848526590 75
767470835438322823191714131110  9  8  8  7  7  7  7  8  8  91011121416182124293645525587 8372
807171807847363228232017151312111110 10  9  9  910101011121314161821242835435151748881 65
7473767082734536322824211816151413121211121212121314161719212529354251516690807365
7563767471836945373229252220181716151514141515161718192123263036435152638882738060
7268797173718373483833312825232120191818181818192021232528323845515163895806468 57
6455687079737182785541363331292625232222222223232526293236424852516687857273687458
7363696970717470808366484036333231302928282829303235384247525155749082797369615947
6154617070807877737284836652444138373636363738404246495252526587888073646862646455
6153546556696474727671758485766557514847474849505150505365839083817379687459645847
5548476153606363696669646362687273716763585554545763758687817371646459555847554739
```

MINIMUM LITF= 0.68131146E+00 MAXIMUM LITF= 0.22452025E+01

These are the values for Calibration of Water(p=1.0) density for Generalised Filter No.4

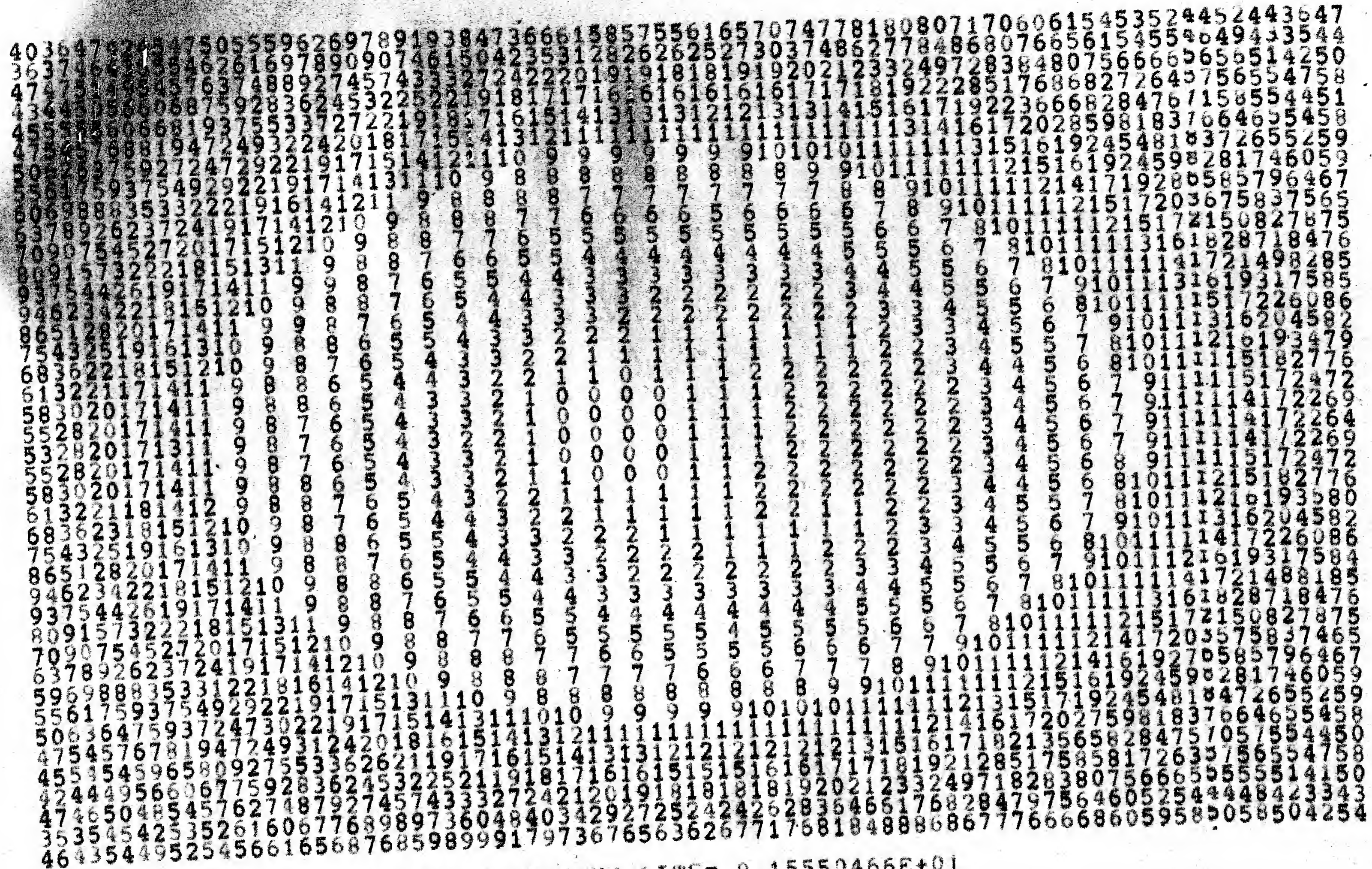
LITF=0.928

```
6458636964697172787681628888898684817874717172747883929899928681787469660360625454
5852576261686873758184888783736254494644434444464954596877909287817575686658565149
6257636768767680848687796451434037353434343135363840424754647791918476716862625757
5862676970747985888264484036333130292828282829303133353841465568889388780736962575
6369687078818686755341353129272524232323232424252628303235384249617792887873686558
6867757380868569463732292623222121212121212222232425262830333364046597593580716761
7067757885856644353026232120202019191919192020212223242526293233540455875936577756
7172798485694334292522202019181817171717171718181921222324262831353945597394857569
7673828774463529252120191817171616151515151516161718192123242628313540476385938274
7580848152373025212019181716151514141414141414151516171820222426283236425169938777
8082856340312622201918171615141413131313121212131314141517182022242629333844577993
8186784734282320191817161514131312121111111111111212131415161820222427303540486928
868562393025211918171615141312111110 10  9  9  91010111111121314161820232528323743567995
868049342722201817161514131211 10  9  9  8  8  8  9  9  91010111112131517192124262934404969
8770413125211918161514131211  9  8  8  8  7  7  8  8  8  9  910101111131415172023252832384561
8560372923201917161413121110  8  8  7  7  7  7  7  7  7  8  9  910111121315161922242730364255
83523527222018161514131210  9  8  7  7  7  7  7  7  7  7  8  9  9101111131416182024262935415173
81463326211918161515131211  9  8  7  7  7  7  6  6  5  6  6  7  7  8  91011112131517202326283339
78433225201917161413121 1  9  8  7  7  7  6  5  4  3  4  5  6  7  8  910111121315171922252833384666
76413125201917161413121 0  9  7  7  7  6  5  4  2  2  3  4  6  7  8  8  91012131517192225283238 4564
73413025201917161413121 0  8  7  7  7  6  5  3  2  0  2  4  6  7  8  8  9101111314161922252732374563
76413125201917161413121 0  9  7  7  7  6  5  4  2  2  3  4  6  7  8  8  91012131517192225283238 4564
78433225201917161413121 1  9  8  7  7  7  6  5  4  4  4  5  6  7  8  910111121315171922252833394666
81463326211918161514121 1  9  8  7  7  7  7  6  6  5  6  6  7  8  8  9101111213151720232628343948 69
835235272220181615141312 10  9  8  7  7  7  7  7  7  7  7  7  8  9101011131416182124262935415173
8560372923201917161413121110  8  8  7  7  7  7  7  7  8  8  9  910111121315171922242731364355 79
877041312521191816151413121110  9  8  8  8  8  8  8  8  9  9101112131416182023252832384561 88
868149342822201917161514131211 10  9  9  8  8  8  9  9  910111111121415171921242630344049 6994
868562393025211918171615141312121110 10  9  91010101011121213151618202325283237435679 95
9186784634282320191817161514131312121111111111111212131415161820222427303540486928 8
8082856340312622201918171615141413131313121212131314141517182022242629333844577993 83
7580848152373025212019181716151514141414141414151516171920222426283236425169938778
7673838774463529252220191818171616161515151616171718192123242628323641486386938274
7172798485694435292622212019191818171717171718181920212224252628323640466079948676 70
7167757986856744363127242221212020202020202122222324262730333640465877948678766 5
6968767481868570473832292624232222222222222324242527283134374147597794989817268 62
6461697179828787755442363230282625242424242525262729313335394350627893887974696658
6962687071758086898265494137343230292929292930313234363842465668859385807469635755
6358646869767681848687806451444038363535343536363840434754647792918577710863625857
5752576160686772748183878682726153484543434344454953596777909286817474670557575048
5953576359646667727176778282838179767269656667697277869394878176726864605754574849
```

MINIMUM LITF= 0.46885256E+00 MAXIMUM LITF= 0.17809863E+01

These are the values for Calibration of Walnut(p=0.73) density for Generalised Filter No.4

LITF=0.740



MINIMUM LITF= 0.34911513E+00 MAXIMUM LITF= 0.15550466E+01

These are the values for Calibration of Pine(p=0.41) density for Generalised Filter No.4

```
1216281525222532354553688283675041343435374552576162585049434635382931292035191634
1624332543355245606883785133242118161413131315192842617678685758464430372133211935
29333328363448638082512923191511 9 7 6 5 5 4 4 4 5 7112345727763595851533840312236
16252838445866856535241913 9 7 7 6 6 5 5 5 5 4 4 3 2 2 3 7184675746055453938393351
2643364549728353272114 9 7 7 6 6 6 5 5 5 5 5 4 4 4 4 3 3 1 2 827657663565639372035
24363458738648251812 8 7 6 6 6 6 6 6 6 6 6 6 6 6 5 5 4 3 3 2 1 5165676613644513644
275348678448251811 8 7 6 6 7 7 7 7 7 7 7 7 6 6 6 6 6 5 5 4 3 3 1 21250766255502946
3446648653261710 7 7 6 6 7 7 7 7 7 7 6 6 6 6 6 6 6 6 5 5 5 4 3 3 1 211567559564344
36618165271810 7 6 6 7 7 7 7 7 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 4 3 2 1 2166473574453
476983362112 8 7 6 7 7 7 7 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 4 3 2 1 42674615650
5584522415 8 7 6 7 7 7 7 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 4 3 2 0 745755660
7079301910 7 6 6 7 7 7 6 6 6 6 6 6 6 6 7 7 6 6 6 6 6 6 6 6 6 6 5 5 4 3 2 216706658
84522414 8 7 6 7 7 7 6 6 6 6 6 7 7 7 7 7 7 7 7 7 6 6 6 6 6 6 6 6 5 5 3 2 1 6437664
85352010 7 6 7 7 7 7 6 6 7 7 7 7 7 7 7 7 7 7 7 7 7 6 6 6 6 6 6 6 6 5 4 3 2 2207464
692716 8 7 6 7 8 7 6 6 7 7 7 7 7 7 7 7 7 7 7 7 7 7 6 6 6 6 6 6 6 6 5 5 3 2 0 85673
522313 8 6 7 7 7 7 6 6 7 7 7 7 8 8 8 8 8 8 8 7 7 7 6 6 6 6 6 6 6 6 5 5 4 2 1 43976
412111 7 6 7 8 7 6 6 7 7 7 7 8 8 8 8 8 8 8 8 8 8 7 7 6 6 6 6 6 6 6 6 5 4 3 2 22577
3319 9 7 6 7 8 7 6 6 7 7 7 7 8 8 8 8 8 8 8 8 8 8 8 7 7 6 6 6 6 6 6 6 5 4 3 2 11675
3018 8 7 6 7 8 7 6 6 7 7 7 7 8 8 8 8 8 8 8 8 8 8 8 7 7 6 6 6 6 6 6 6 5 5 3 2 01173
2817 8 7 6 7 7 7 6 6 7 7 7 7 8 8 8 8 8 7 7 7 8 8 8 8 7 6 6 6 6 6 6 6 5 5 3 2 0 969
2716 8 7 6 7 8 7 6 6 7 7 7 7 8 8 8 8 8 7 7 7 8 8 8 8 7 6 6 6 6 6 6 6 5 5 3 2 0 863
2817 8 7 6 7 7 7 6 6 7 7 7 7 8 8 8 8 8 7 7 7 8 8 8 8 7 6 6 6 6 6 6 6 5 5 3 2 0 969
3018 8 7 6 7 8 7 6 6 7 7 7 7 8 8 8 8 8 8 8 8 8 8 8 7 7 6 6 6 6 6 6 6 5 5 3 2 01173
3319 9 7 6 7 8 7 6 6 7 7 7 7 8 8 8 8 8 8 8 8 8 8 8 7 7 6 6 6 6 6 6 6 5 5 3 2 11676
412111 7 6 7 8 7 6 6 7 7 7 7 8 8 8 8 8 8 8 8 8 8 7 7 6 6 6 6 6 6 6 6 5 4 3 2 22577
522313 8 6 7 7 7 6 6 6 7 7 7 7 7 8 8 8 8 8 8 7 7 7 6 6 6 6 6 6 6 6 5 5 4 2 1 43976
692616 8 7 6 7 7 7 6 6 6 7 7 7 7 7 7 7 7 7 7 7 7 6 6 6 6 6 6 6 6 6 5 5 3 2 0 85773
84351910 7 6 7 7 7 6 6 6 6 6 7 7 7 7 7 7 7 7 7 6 6 6 6 6 6 6 6 6 6 5 4 3 2 2207464
84522414 8 7 6 7 7 7 6 6 6 6 6 6 7 7 7 7 7 7 7 6 6 6 6 6 6 6 6 6 5 5 3 2 0 6437563
7079301910 7 6 6 7 7 7 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 4 3 2 116706658
5584522415 8 7 6 7 7 7 7 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 4 3 2 0 745755660
476983362112 8 7 6 7 7 7 7 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 4 3 2 1 42674615650
36618165271811 7 7 6 7 7 7 7 7 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 4 3 2 1 2166473574453
3346638553251710 7 7 6 6 7 7 7 7 7 7 6 6 6 6 6 6 6 6 5 5 5 4 3 2 1 211567559564344
265248668348251710 7 6 6 6 6 6 7 7 7 7 6 6 6 6 6 5 5 5 4 3 3 2 1 21150756254492846
24363458728648251812 8 7 6 6 6 6 6 6 6 6 6 6 6 5 5 4 4 3 3 2 0 4165676615544513644
2643354449728352262014 9 7 6 6 5 5 5 5 5 5 4 4 4 3 3 3 2 1 2 727647662565638361935
15252737445766856435231813 9 6 6 5 5 5 4 4 4 4 3 3 2 1 3 7174674745954443937393250
27323227343246617981502821171310 7 6 5 4 3 3 2 3 4 6 92144717662585650513638292034
1623322542345145596882775033232018161413121214182842607677675757454429362032211834
2932443241394249516270859899836657515151536268747878756666606252555454474536513535 50
```

MINIMUM LITF=-0.15849042E+00 MAXIMUM LITF= 0.14964145E+01

These are the values for Calibration of Air(p=0.0) density for Generalised Filter No.4

LITF=0.00

```
635357695868696975711797377758284848277736765646569758899988979777271666364546452 50
524246554761546664716874618169564740373737383941424446516383867571647259665056 4639
564656663637470747173827858433534333231313132323335384144465065878673665961555 9652
685563626365697080806039343230292726262525262627272830323639444754758975720763 555243
584763637571748274463432302825242322212121212122232426293135414548666888066761 6652
676174647171826739333127252322201918181818181818192021232629323844486390807360 6151
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7481433328242017151413111010101213141312111010 9 910101111111213141618202429364554 89
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8346332823191715141210101215161 3 8 5 3 2 3 3 3 4 4 5 6 6 7 8 910121416182226354557
833932272219161413111010131514 9 4 2 1 1 2 3 3 4 4 5 5 6 7 8 910111315182127334351
803631262218161413111011141512 6 2 0 1 2 3 3 4 4 5 5 6 6 7 8 910111315172026334249
773531262118151413111011141510 4 1 0 2 3 3 4 4 4 5 5 6 6 7 8 910111315172025324248
733531252118151413101011141510 4 1 0 2 3 4 4 4 4 5 5 6 6 7 8 910111315172025324248
773531262118151413111011141510 4 1 0 2 3 4 4 4 4 5 5 6 6 7 8 910111315172025324248
803731262218161513111011141512 6 2 0 1 3 3 4 4 4 5 5 6 6 7 8 910111316182026334249
843932272319161514121011131614 9 5 2 1 2 3 3 4 4 5 5 6 7 7 9 910111316182127344452
8346332823201715141211101215161 3 9 5 3 3 3 3 4 4 5 5 6 7 8 9 910121416182226364557
8256342924201715141311101113151515 13 9 7 5 4 4 4 5 5 6 6 7 8 91011121417192330384665
79693430252118151413111 0 910121414131 0 9 7 6 6 6 6 7 7 8 9 91011131617202532414877
738042322722191614131210 8 8 91112121211 10 9 9 8 8 8 9 9101111111315171922283544 5388
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564756646374717571738279594335343332323231323334363841444751668886746660015659 5653
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```

MINIMUM LITF= 0.51906198E+00 MAXIMUM LITF= 0.25836699E+01

These are the values for Scan 6 of 90%(p=0.9) density for Shepp and Logan filter.

LITF=1.230

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625155675767686977738074787782848382767267656466707688999898077737164626354645250
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766573817338312623201816141312111010 10 9 9 9 91010111112131516192228354350 76877462
727275804532272320181514121110 9 9 8 8 8 8 8 8 8 9 91011121314161923293745558978 67
7970825933292421181513121110 9 8 8 7 7 7 7 7 7 8 8 9 9101113141619243139476789 69
737678383125211816141210 9 8 8 7 7 6 6 6 6 6 6 6 7 7 8 8 910111315172026344352 8679
7782573328232017141211 9 8 7 7 6 6 6 5 5 5 5 5 6 6 6 7 7 8 91012131518222939476789
7580423125211815131110 8 7 7 6 6 5 5 5 5 5 5 5 5 5 6 6 7 7 8 911121416202634445590
80683329232016141210 9 8 7 6 6 5 5 5 4 4 4 4 4 4 5 5 5 6 7 8 910111315182331414979
825432272218151311 9 8 7 6 6 5 5 4 4 3 3 3 3 4 4 4 5 5 6 6 7 8 911121417212837 4767
834531252117141210 9 7 7 6 5 5 4 3 3 3 3 3 3 4 4 5 5 6 7 8 91012141620263545 59
823730242017141110 8 7 6 5 5 4 3 3 2 2 2 2 3 3 3 4 4 5 5 6 6 7 810111113151924334354
7835292320161311 9 8 7 6 5 5 4 3 2 2 2 1 2 2 3 3 4 4 4 5 6 6 7 8101113151823324251
7634292319161311 9 8 7 6 5 4 4 3 2 2 1 1 1 1 2 3 4 4 4 5 5 6 7 8 91113151623314150
7233282319161311 9 8 7 6 5 4 4 3 2 2 1 1 0 1 2 3 4 4 4 5 5 6 7 8 91113151722314150
7634292319161311 9 8 7 6 5 4 4 3 2 2 1 1 1 1 2 3 4 4 4 5 5 6 7 8 91113151623314150
7935292320161311 9 8 7 6 5 5 4 3 2 2 2 2 2 3 3 4 4 5 5 6 6 7 8101113151823324251
833830242017141210 8 7 6 6 5 4 4 3 3 2 2 2 3 3 4 4 4 5 5 6 7 7 810111315192433 4354
834531252117151210 9 8 7 6 5 5 4 4 3 3 3 3 3 3 4 4 4 5 5 6 7 8 91012141620263545 60
825532272218151311 9 8 7 6 6 5 5 4 4 4 3 3 3 4 4 4 5 5 6 6 7 8 911121417212837 4767
80683329232016141210 9 8 7 6 6 5 5 4 4 4 4 4 4 4 5 5 5 6 7 8 910111315182331414979
7580423125211815131110 8 7 7 6 6 5 5 5 5 5 5 5 5 6 6 7 7 8 911121416202634445590
7782573328232017141211 9 8 7 7 6 6 6 5 5 5 5 5 6 6 6 7 7 8 91012131518222939476789
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727275804532272320181514121110 9 9 8 8 8 8 8 8 8 9 91011121314161923293745558978 67
766573817338312623201816141312111010 9 9 9 9101011111213151619222835435076877462
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5342485650645869677572788482715748413938383941424446495556786897873677361075258 4741
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```

MINIMUM LITF= 0.51920851E+00 MAXIMUM LITF= 0.24996393E+01

These are the values for Scan 6 of 80% (p=0.80) density for Shepp and Logan Filter.

LITF=1.03

```
6049546557666868767381778079848483897571666565677177899998897976727064626253625149
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5446566362747277757682765640323029262727272728303235394347546989877566605154585651
6655626264687374827957373129272524232221212122222426283237434958789177730763565243
5748626477747782714431282624222018171716161717181820212427323845527090820867626752
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68677774826534282522181614121110 9 9 8 8 8 8 9 9 9101113151821253241507091766761
7567758171362925211815131110 8 8 7 7 7 7 7 7 8 8 8 9 910121417202532425278877362
727476794430252117151210 9 8 7 6 6 6 5 5 5 5 6 6 7 8 9 9 910121418212635455890 7967
807282573127221815121 0 9 7 6 6 5 5 5 5 4 4 4 4 5 5 6 7 8 9 910121518222838486699071
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798156312621171311 9 7 6 6 5 5 4 4 3 3 3 3 3 3 3 3 3 4 5 6 8 9 9101317212737487090
777940292419151210 8 6 6 5 5 4 3 3 3 2 2 2 2 2 2 3 3 3 4 5 6 8 9 911141924324 45891
8167322722171311 9 7 6 5 5 4 3 3 2 2 2 2 1 2 2 2 2 3 3 3 4 5 7 8 91013172128395181
8253302520161210 8 6 6 5 4 3 3 2 2 1 1 1 1 1 1 1 2 2 3 3 3 4 6 8 9 912152026354770
82432924191411 9 7 6 5 5 4 3 2 2 1 1 1 1 0 0 1 1 1 2 2 3 3 4 5 7 9 911141824334562
81362823181411 8 7 6 5 4 3 3 2 2 1 1 1 0 0 0 0 0 1 1 2 2 3 3 4 6 8 910131622304356
77332722171310 8 7 6 5 4 3 2 2 1 1 1 1 0 0 0 0 0 0 1 2 2 3 3 4 6 8 910131721294153
74322722171310 8 6 6 5 4 3 2 2 1 1 1 0 0 1 0 0 0 0 1 1 2 3 3 4 5 8 9 9121621284052
71322721161310 8 6 5 5 4 3 2 2 1 1 1 0 1 1 0 0 0 0 1 1 2 3 3 4 5 8 9 9121621283952
74322722171310 8 6 6 5 4 3 2 2 1 1 1 0 0 0 0 0 0 1 1 2 3 3 4 5 8 9 9121621284052
77332722171310 8 7 6 5 4 3 2 2 1 1 1 0 0 0 0 0 0 1 2 2 3 3 4 6 8 910131721294153
81362823181411 8 7 6 5 4 3 3 2 1 1 1 1 0 0 0 0 1 1 2 2 3 3 4 6 8 910131822304356
82432924191411 9 7 6 5 4 4 3 2 2 1 1 1 1 0 0 0 1 1 2 2 3 3 4 5 7 9 911141824324562
8253302520161210 8 6 6 5 4 3 3 2 2 1 1 1 1 1 1 1 2 2 3 3 3 4 6 8 9 912152026354770
8167322722171311 9 7 6 5 5 4 3 3 2 2 2 2 1 2 2 2 2 3 3 3 4 5 7 8 91013172128395181
777940292419151210 8 6 6 5 5 4 3 3 3 2 2 2 2 2 3 3 3 4 5 6 8 9 911141924324 45891
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MINIMUM LITF= 0.49546118E+00 MAXIMUM LITF= 0.24181408E+01

These are the values for Scan 6 of 70% (p=0.7) density for Shepp and Logan Filter.

LITF=0.86

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6563757079798264373026222018171514131313121213131314151720232734435471948475636254
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696980798364342823201715131110 9 9 9 8 8 8 8 8 91011121213141620253141537493786961
76707984713728232017141210 9 9 8 8 7 7 7 7 7 7 7 8 8 91112131416202532435682907765
747881794530242017141210 9 8 8 7 6 6 5 5 5 5 5 5 6 6 7 81011121416202634466391827 0
8277835832262118151210 9 8 7 6 6 5 5 4 4 4 4 4 4 5 5 6 7 8 91112141622273851749273
7981763828221915121 0 9 8 7 6 5 5 4 4 3 3 3 3 3 3 3 4 4 5 6 7 911131418233143599083
84835631252017131 1 9 8 7 6 5 5 4 3 3 2 2 2 2 2 2 2 3 3 4 5 6 7 9121315202636517492
8279412822181512 10 9 8 6 5 4 4 3 2 2 1 1 1 1 1 1 2 2 3 3 4 5 6 8101214172331446293
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8354302419151210 9 7 6 5 4 3 2 1 1 1 1 1 1 1 1 1 1 1 2 3 4 5 6 81012141825355074
82442922181411 9 8 7 5 4 3 2 1 1 1 1 1 1 1 1 1 1 1 1 2 2 3 4 5 7 912131723314666
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77342620171310 9 7 6 5 4 2 1 1 1 1 0 0 0 0 0 1 1 1 1 1 1 2 3 3 5 6 811131521284158
74332620161210 9 7 6 5 3 2 1 1 1 1 0 0 0 0 0 0 1 1 1 1 1 2 2 3 4 6 811121520274056
71322620161210 9 7 6 5 3 2 1 1 1 1 0 0 0 0 0 0 1 1 1 1 1 2 2 3 4 6 810121420263956
74332620161210 9 7 6 5 3 2 1 1 1 1 0 0 0 0 0 0 1 1 1 1 1 2 2 3 4 6 811121520274056
77342620171310 9 7 6 5 4 2 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 2 3 4 5 6 811131521284158
81372721171311 9 8 6 5 4 3 2 1 1 1 1 1 1 1 1 1 1 1 1 1 2 3 4 5 7 811131522294361
82442922181411 9 8 7 5 4 3 2 1 1 1 1 1 1 1 1 1 1 1 1 2 2 3 4 5 7 912131723314667
8354302419151210 9 7 6 5 4 3 2 1 1 1 1 1 1 1 1 1 1 1 2 3 4 5 6 81012141825355074
8467322620171310 9 8 7 6 5 4 3 2 1 1 1 1 1 1 1 1 1 2 2 3 4 5 7 91113152027395584
8279412822181512 10 9 8 6 5 4 4 3 2 2 1 1 1 1 1 1 2 2 3 3 4 5 6 8101214172331446293
848356312520171311 9 8 7 6 5 4 4 3 2 2 2 2 2 2 2 2 3 3 4 5 6 7 9111315202636517492
798176372822181512 10 9 8 7 6 5 5 4 4 3 3 3 3 3 3 3 4 4 5 6 7 911121418233043599082
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5245495653656272738180848581695647403837373840424549546274909182766972620554564743
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MINIMUM LITF= 0.39276170E+00 MAXIMUM LITF= 0.22719101E+01

These are the values for Scan 6 of 60% (p=0.6) density for Shepp and Logan Filter.

LITF=0.73

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66616074667376758178827877776828586848077726968687177889999958785787873707161686052
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7574787383744839343127242220191817171616151617171819202122242731374352536791817567
8073738179514034302623211918171616151514141415151516171920222426313744535375898367
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7775825133332823201816151312101010101111111212121213131414161720222429354353548484
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844937322622191716131213161814  7  2  0  1  3  3  4  4  5  5  6  7  7  8101112131518212531405253
824736322622181715131214171812  5  1  0  2  3  4  4  5  5  6  6  7  7  8101112131518212431395152
794736312522181716131214171712  5  1  0  2  4  5  4  5  5  6  6  7  7  8101112131518212431385153
824737322622191715131214171813  5  1  0  2  3  4  4  5  5  6  6  7  8  8101112131518212431395152
854937322622191816131213171814  7  3  1  1  3  4  4  5  5  6  6  7  8  9101112131619212532405253
86523833272320181614121316181711  6  3  2  2  3  4  4  5  6  6  7  8  9101112141619222633415354
8658403428242018171513121418191510  6  4  3  3  4  4  5  5  6  7  8  91011131417202227344353 59
846543352925211917151312131618181511  8  6  5  5  5  5  6  7  7  8  911121315172023283646 5366
8075463631252119171613121113151617151210  9  8  7  7  7  8  9101011121416192125313850 5377
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7583674335302521181715141210101011121313121212121212131314141618202225313848546788
7776825239342824211817161412111010111112121212121213131414151618202225293543545 58585
8272836945363227232018171615131211111111111212121313131415161820222427334050546791 77
7777728457413531262320181716161514131312121313131314151618192123263138465457878575
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7574787383744839343127242220191817171616161617171819202122242731374352536791817567
7664777774847148403532292624222120191918191919202021222426293338445254648884758162
7269797375738474514136333128262423222221212122222324252831353946535364906826 67059
6557697180757383795845393533312927262525252525262729323538434953536787867475697560
7465707071737777381846952444036343332323131313233353739434853545775918481757163 6150
6154617170807879747384836855474341393838383940414447515354546787898175669636565 57
6154556557706575747873778586776759545149495051525353535667849184837581697561645949
5550496254626564696771676564707474726965605857576066768788837573666662580050564841
```

MINIMUM LITF= 0.52278121E+00 MAXIMUM LITF= 0.22176911E+01

These are the values for Scan 6 of 90%(p=0.9) density for Generalised filter.

LITF=0.843

```
6458587165727575682808478787782858583807672686868727888888858785787771687060676052
5852536357686575747873778484766557514847474848505152535767848084827478687260635748
5853606870807878757483816653444038363533434353638414449525355678688817466086163635 6
7163697072747774818367504237333130292828272828303234374247535458769184817469626050
6457707281777583785643363230282625232322222222232426293236424953556989877575697360
7269807477748473504034312825232221201919181819192021222528323845525466918782676959
7565787875847047383229262321201817161615151515161617182022252935425154668884758062
7575797483734737322825222018161514141313131313131415161718202328344251546991827567
8174758278503832282421191715141312121111111111111213131516172022273442525476898368
797874835640322824211816141312111010 9  9  9  9 9101011121314151719222835445358878575
8373836743342915211816141311 10  9  9  8  8  8  8  8  9  9101112131517202329374854689177
787781503731262219161412111 0  9  8  8  7  7  7  7  7  7  8  8  91011121315172025324152568585
7784664233282320171413111 0  9  8  7  7  6  6  6  6  6  6  7  7  8  9101112141618222735475468 89
76835337312521181513111 0  9  8  7  7  6  6  6  5  5  5  5  6  6  6  7  8  9101113151720243141535889
817544342823201714121 0  9  8  7  6  6  6  5  5  5  4  5  5  5  5  6  6  7  8  9101213161822283750 5478
8464413226221151311  9  8  7  6  6  5  5  4  4  4  4  4  4  4  5  5  6  6  7  8  9111315172025344554 68
85563830252117141210  9  8  7  6  5  5  4  3  3  3  3  3  4  4  4  5  5  6  7  8  9101214161924314253 61
8450352924201614111 0  8  7  6  6  5  4  3  3  2  2  2  3  3  4  4  5  5  6  7  7  91011131618222940 5356
834734282319161311  9  8  7  6  5  4  3  3  2  2  1  2  2  3  4  4  5  5  6  6  7  81011131518222838 5155
814534282319151311  9  8  7  6  5  4  3  2  2  1  1  1  1  2  3  4  4  5  6  6  7  8  9111315182128375154
784533282319151311  9  8  7  6  5  4  3  2  2  1  1  0  1  2  3  4  4  5  6  6  7  8  9111315182127375055
814534282319151311  9  8  7  6  5  4  3  2  2  1  1  1  1  2  3  4  4  5  5  6  6  7  81011131518212837 5154
834734282319161311  9  8  7  6  5  4  3  3  2  2  2  2  2  3  4  4  5  5  6  6  7  810111315182228385155
8550362924201614121 0  8  7  6  6  5  4  3  3  2  2  3  3  3  4  4  5  5  6  7  8  91012131619223040 5357
85563831252117141210  9  8  7  6  6  5  4  3  3  3  3  3  4  4  4  5  5  5  6  7  8  9101214161924314253 61
8464413226221815131 1  9  8  7  7  6  5  5  4  4  4  4  4  4  4  5  5  5  6  6  7  8  9111315172025344554 68
817544342823201714121 0  9  8  7  6  6  6  5  5  5  4  4  5  5  5  6  6  6  7  8  91012131618222837505478
768353373025211815131110  9  8  7  6  6  6  6  5  5  5  5  6  6  6  7  8  9101113141720243141535889
7784664233282320171413111 0  9  8  7  7  6  6  6  6  6  6  6  7  7  8  9101112141618222735475468 89
787781503731262219161412111 0  9  8  8  7  7  7  7  7  7  7  8  8  91011121315172025324152568585
83738367433429252119161413111 0  9  9  8  8  8  8  8  8  9  9101112131517202329374854689177
7978748356403228242118161413121110 10  9  9  9  9101011121314151719222735445358878575
8174758278503832282421191715141312121111111111111213131416172022273442525476898368
7575797483734737322824222018161514141313131313131415161718202328344151546891827567
7565787875847047373229262321201817161615151515161617182022252935425154668884758061
7169807476748373493933302725232120191918181818191920222427323745525466908682676958
6457707281767583785643363230282624232222222222232426283236414853546988867575697359
7164697072747874818367504237343230292828282829303234374247535459769184827570636050
5954617071817980767584826754454239373636363738404246505354566888908276670963646457
5953546458706676757974788585776658524948484950515253545886885918583758069736164584 9
5448486154616585716973696866717574736965615858586167778888847674676661589494956494 2
```

MINIMUM LITF= 0.52507500E+00 MAXIMUM LITF= 0.21514470E+01

These are the values for Scan 6 of 80%(p=0.8) density for Generalised filter.

LITF=0.779

```
6357577165727575818185828180848685837976717069697379899999958783777671697060655951
585254645869667575768176797848374645550474545464850515354596985918583747869725962574 7
5754606969797981787583806551423835333232323334363943485254576988898274660862636254
7164697073768077838366494035323029282726262627283032353946535661789285827570646150
6558697382797783765541343129272422212020202020212224262933394753577189887674707360
7269797779778472483832292623211918171615151516161819212326303543525668928782676959
7466798077846946363128242119171514131312121212121314161821232732405156689085767963
7476817783724535302722191715131211111010101010111111121416182226313951567192837568
807677837648353026211816131210 9 9 8 8 8 8 8 9 91010111111215182125313951567890836 8
79817683553830272118151311 9 8 8 7 7 7 6 6 7 7 8 8 91011111121417212632435361898675
847683664132282218151211 9 8 7 7 6 6 5 5 5 5 5 6 6 7 810111111214182227344755709278
8179804934292419161311 9 8 7 6 6 5 5 5 4 4 4 4 4 5 5 6 8 9111112151923303952588786
80846540312620171311 9 8 7 6 6 5 4 4 4 3 3 3 3 4 4 4 5 6 7 91111131620263345557191
78825135292318151210 8 7 6 5 5 4 3 3 3 3 3 3 3 3 4 4 5 6 71011121418232939536191
827343322721161310 9 7 6 6 5 4 3 3 2 2 2 2 2 2 3 3 4 4 5 6 810111216212634485781
8463393025191512 9 8 7 6 5 4 3 3 2 2 1 1 1 1 1 2 2 3 3 4 4 5 7 9111214192431445571
8454352923181411 9 7 6 5 5 4 3 2 2 1 1 1 1 1 1 1 2 3 3 4 5 6 8101113172229405464
8349332821171310 8 7 6 5 4 3 3 2 1 1 1 1 0 0 0 1 1 2 3 3 4 5 7101112162128375259
8245322721161310 8 7 6 5 4 3 2 2 1 1 1 1 0 0 0 0 0 1 2 3 3 4 5 7101112152026355157
7944322720161210 8 7 6 5 4 3 2 1 1 1 1 1 1 0 0 0 0 1 2 2 3 4 5 7 91112152026345056
7643312620161210 8 7 6 5 4 3 2 1 1 1 1 1 1 0 0 0 0 1 2 2 3 4 5 6 91112152026344957
7944322720161210 8 7 6 5 4 3 2 1 1 1 1 1 1 0 0 0 0 1 2 2 3 4 5 7 91112152026345056
8245322721161310 8 7 6 5 4 3 2 2 1 1 1 0 0 0 0 0 0 1 2 3 3 4 5 7 91112152026355157
8349332821171310 8 7 6 5 4 3 3 2 1 1 1 0 0 0 0 1 1 2 3 3 4 5 7101112162127375259
8454352923181411 9 7 6 5 4 4 3 2 2 1 1 1 1 1 1 1 2 3 3 4 5 6 8101113172229405464
8463393024191512 9 8 7 6 5 4 3 3 2 2 1 1 1 1 1 2 2 3 3 4 4 5 7 9111214192431445571
827343322721161310 9 7 6 6 5 4 3 3 2 2 2 2 2 2 3 3 4 4 5 6 810111216212634485781
78825135292318151210 8 7 6 5 5 4 3 3 3 3 3 3 3 3 4 4 5 6 71011121418232939536191
80846540312620171311 9 8 7 6 6 5 4 4 4 3 3 3 3 4 4 4 5 6 7 91111131620263345557191
8179804934292419151310 9 7 7 6 6 5 5 4 4 4 4 4 4 5 5 6 8 9101112151923293952588786
847683664132282218151210 9 8 7 7 6 6 5 5 5 5 5 6 6 7 810111111214182227344755709278
8081768355383127211815131110 8 8 7 7 7 7 7 7 7 8 810101112121417212632435461898675
807778837748363026221816141211 10 9 9 9 8 9 9 910101111112131518212631405257789184 69
7476817783724535302722191715131211111010101010111111121416182226313951567192837568
746679807783684535312824201816151413121212121212131416182023273239505668985757962
7269797679778372483831292623201917171615151516161719212326293443525668928782676959
6558697382797783775541353129272523212120202020222324262933394754577190887674707460
7064687072768077828266494035313029282726262627282931343945525561789285827470636150
5955617071808082797784816652443937353433333435374041495355587189918376677063646355
5953556659706777788277808684756557514847474849515354566071879286847579707461635949
5348486155626566727176727170747676737066626060606369798989857774676762596050564942
```

MINIMUM LITF= 0.49532907E+00 MAXIMUM LITF= 0.20743750E+01

These are the values for Scan 6 of 70%(p=0.7) density for Generalised filter.

LITF=0.70

```
6158586964717476818187868584868785827976727171727581909999958785777571676760635752
5753546259706978808481838582736355504745454648505255586474889287847578687061615649
5754606871798184828084796451423835323131313132343741475257627489928478690863626155
6863697174798481848265493934302826252524242425262830333744525866829488837570636153
6359717484838285765541342927242321201919191819192123252832374655617591897876697261
7070797983818471483730272422201817161615151515161617182124283341525973946984697061
7469818481846845342825221917161413121212121213131414151618212630385058729188787964
75778481847145342824211816141211111010101010101111123141516172024303750597594857768
81808284764834282420171513111010 9 9 8 8 8 8 8 8 910111214151719243039526182928671
8184308255372924201714121110 9 8 8 7 7 6 6 6 6 7 7 8 91011131517192431415566908978
87818466413025211814121110 9 8 7 6 6 5 5 5 5 5 5 5 6 7 8 9111315172026334658759481
858279493427221815121110 9 7 6 6 5 4 4 4 3 3 3 4 4 5 5 6 7 91113151721283753628989
8485644029242016131110 9 7 6 5 4 4 3 2 2 2 2 2 2 3 3 4 5 6 7 911141618243144587593
83825134272218141210 9 8 6 5 4 3 2 2 1 1 1 1 1 1 2 2 3 4 5 6 7 9121417212838536592
857343302520161311 9 8 7 5 4 3 2 2 1 1 1 1 1 1 1 2 2 3 4 5 6 81013151825324 86084
856238282318151210 9 7 6 5 3 2 1 1 1 1 1 1 1 1 1 1 2 2 3 4 5 7 91215172230425775
845434272117131110 8 6 5 4 2 1 1 1 1 1 1 1 1 1 1 1 2 3 4 5 6 81114162027385469
8249322620161311 9 7 6 5 3 2 1 1 1 1 1 0 1 1 1 1 1 1 1 1 2 3 4 6 81013151926355364
8146312520161210 9 7 6 4 3 1 1 1 1 0 0 0 0 1 1 1 1 1 1 2 3 4 6 71013151825335062
7844302419151210 9 7 5 4 2 1 1 1 1 0 0 0 0 0 1 1 1 1 1 2 3 4 5 7 912151624334961
7643302419151210 9 7 5 4 2 1 1 1 1 0 0 0 0 0 1 1 1 1 1 2 3 4 5 7 912151724324861
7844302419151210 9 7 5 4 2 1 1 1 1 0 0 0 0 0 1 1 1 1 1 2 3 4 5 7 912151824334961
8146312520161210 9 7 6 4 3 2 1 1 1 0 0 0 0 0 1 1 1 1 1 1 2 3 4 6 71013151825335062
8349322621161311 9 8 6 5 3 2 1 1 1 1 1 1 1 1 1 1 1 1 1 2 3 4 6 81013161926355364
845435272117131110 8 6 5 4 2 2 1 1 1 1 1 1 1 1 1 1 1 2 3 4 5 6 81114162028385469
856238282318151210 9 7 6 5 3 2 1 1 1 1 1 1 1 1 1 1 2 2 3 4 5 7 91215172230425775
857343302520161311 9 8 7 5 4 3 2 1 1 1 1 1 1 1 1 1 2 2 3 4 5 6 81013151825324 86084
83825134272218141210 9 7 6 5 4 3 2 2 1 1 1 1 1 1 2 2 3 4 5 6 7 9121416202737536592
8485644029242016131110 9 7 6 5 4 4 3 2 2 2 2 2 2 3 3 4 5 6 7 911141518243144577593
848279493327221815121110 8 7 6 5 5 4 4 3 3 3 3 3 4 4 5 6 7 91113151721283752628989
86818465413025211714121110 9 8 7 6 5 5 5 4 4 5 5 5 6 7 8 9111315162026334658749481
8184808255372824201714121110 9 8 7 7 6 6 6 6 6 6 7 8 81011131516192431415566908978
81808284764834282420171512111010 9 9 8 8 8 8 8 8 910111214151719243038526182928670
757784818471453428242118161412111110101010101011111113141516172024303850597594857768
7469818482846846352925222018161513131212121313141415161718222631395059739188788064
7070797983818471483730272422201817161515151515151616171820242833415259729489846969 60
6359717484838184765441332926242221201918181818192022252831374654607591897876697161
6863697175808481858266494034302827262524242525272830333845535866829488847571636153
5855616971808185838185806552433935333232313233353842485358627490928578690964636256
5955556460727079818682848684746456514847464749525456606575899488857779697162625750
5351516157636768747480787876797977747168646364646874829192888077706864600053554944
```

MINIMUM LITF= 0.39471290E+00 MAXIMUM LITF= 0.19542150E+01

These are the values for Scan 6 of 60%(p=0.6) density for Generalised filter.

LITF=0.59

```
C         This Program Generates the Data that is to bo employed
C         in the 'New Algorithm' for testing it.This uses a NAG
C         library routine D01AKF which does Integration over any
C         defined limits.The function is to be specified by the us
          EXTERNAL F
          DIMENSION W(800),IW(200),RESULT(11)
          COMMON TH(11)
          OPEN(UNIT=24,ACCESS='SEQIN',FILE='THETA')
          READ(24,*)( TH(I),I=1,11)
          A=0.0
          DO 10 I=1,11
          B=COSD(TH(I))
          EPSREL=0.00001
          EPSABS=0.00001
          CALL D01AKF(F,A,B,EPSABS,EPSREL,RESULT(I),
     1    ABSERR,W,800,LW,200,IFAIL)
10        CONTINUE
          DO 29 I=1,11
29        RESULT(I)=2.0*RESULT(I)
          OPEN(UNIT=21,ACCESS='SEQOUT',FILE='DATA')
          WRITE(21,9)(RESULT(I),I=1,11)
9         FORMAT(11E11.5)
          STOP
          END
          FUNCTION F(X)
          COMMON TH(11)
          Y=SIND(TH(I))
          F2=SQRT(X*X+Y*Y)
          F=EXP(-F2)
          RETURN
          END
```

```
C         This Program Generates the Data for the 'New Algorithm'.
C         The NAG library routine used is the D01AHF routine.
C         The Function is to be specified by the user.
C         PROGRAM FOR INTEGRAL EQN
          REAL A,B,EPSR,RELERR,TH,DT
          INTEGER IFAIL,NLIMIT,N
          REAL D01AHF
          EXTERNAL FUN
          COMMON TH
          A = 0.0
          NLIMIT = 0
          EPSR = 1.0E-5
          IFAIL = 0
          DT= 8.5
          DO 10 I =1,11
          TH = FLOAT(I-1)*DT
          B = COSD(TH)
          ANS = D01AHF (A,B,EPSR,N,RELERR,FUN,NLIMIT,IFAIL )
          ANS=2.*ANS
          WRITE (21,9) ANS
 9        FORMAT(11E11.5)
 10       CONTINUE
          STOP
 50       FORMAT (5X,'THETA=',F4.1,5X,'INTEGRAL=',F8.6,10X,
          1'ESTIMATED ERROR='E15.5,3X,'IFAIL=',F5.3)
          END
          REAL FUNCTION FUN(X)
          REAL X,K
          COMMON TH
          K = SIND(TH)
C         FUN = EXP(-(SQRT((X*X) + (K*K))))
          fun=1.0
          RETURN
          END
```

```
c          This Program Generates Data for specific f(r)=r in
c          order to test the 'New Algorithm'.This doesnot utilise
c          the NAG library routine.
           dimension th(11),r(11)
           open(unit=21,access='seqin',file='tneta')
           read(21,*) (th(i),i=1,11)
           do 10 i=1,11
           y=(1+cosd(th(i)))/sind(th(i))
10         r(i)=cosd(th(i))+((sind(th(i))*sind(th(i)))*alog(y))
           open(unit=23,access='seqout',file='newdat')
           write(23,9) (r(i),i=1,11)
9          format(11e11.5)
           stop
           end
```

```
C         This Program  solves for X using the relation JX=D
C         Before this J is calculated using the formula for J
C         This Program also includes printing of f(r) i.e.,
C         Function Values and errors in Reconstruction E.

          DIMENSION WKS(22),A(11,11),D(11),TH(11),R(11)
          DIMENSION RV(11),C(11,11),Z(11),F(11),W(44),X(11)
          LOGICAL SVD
          N=11

          OPEN(UNIT=21,ACCESS='SEQIN',FILE='THETA')
          OPEN(UNIT=22,ACCESS='SEQIN',FILE='POINTS')
          OPEN(UNIT=23,ACCESS='SEQIN',FILE='DATA')

          READ(21,*) (TH(I),I=1,11)
          READ(22,*) (Z(K),K=1,11)
          READ(23,*) (D(J),J=1,11)

          DO 10 I=1,11
          Q=COSD(TH(I))
          C(1,I)=2.*Q
          DO 20 J=2,N
          C(J,I)=((2.*Q)/(2.*(FLOAT(J))-1.))*(1.+
     1    (((J-1)*(1.-Q*Q)/Q)*C(J-1,I)))
20        CONTINUE
10        CONTINUE

          TOL=5.*10**(-4)
          DO 19 K=1,11
19        R(K)=1.0
          DO 29 I=1,11
          DO 29 J= 1,N
29        A(I,J)=C(J,I)
          OPEN(UNIT=23,ACCESS='SEQOUT',FILE='RESULT')
          WRITE(23,9) A
          IF=0
          CALL F04JGF(11,11,A,11,D,TOL,SVD,SIGMA,IRANK,W,44,IF)
          X=D
          WRITE(5,*) SVD,D,IRANK
8         FORMAT(1X,4E10.4)
          DO 50 I=1,11
          DO 60 J=1,11
          Y=Z(I)*Z(I)
          RV(I)=(RV(I)*Y)+D(12-J)
60        CONTINUE
50        CONTINUE
          DO 59 I=1,11
59        E(I)=RV(I)-R(I)
          WRITE(23,9) X
          WRITE(23,9) R,E
C         This is the desired Reconstruction output
C         RV represents the Reconstruction
          OPEN (UNIT=55,FILE='OUTPUT',ACCESS='SEQOUT')
          WRITE(55,7)(RV(J),J=1,11)
9         FORMAT(11E11.5)
7         FORMAT(1E11.5)
          CLOSE (UNIT=55)
          STOP
          END
```

```
C       This Program checks the accuracy of solving JX=D
C       using NAG library routine by recalculating D.
        DIMENSION A(11),B(11,11),C(11),Z(11)
        OPEN(UNIT=23,ACCESS='SEQIN',FILE='RESULT')
        READ(23,9) ((B(I,J),I=1,11),J=1,11)
        READ(23,9) (C(I),I=1,11)
        DO 10 I=1,11
        DO 10 J=1,11
        A(I)=A(I)+B(I,J)*C(J)
10      CONTINUE
        OPEN(UNIT=24,ACCESS='SEQOUT',FILE='DSTAR')
        WRITE(24,9) A
9       FORMAT(11E11.5)
        STOP
        END
```

```
C     This Program Regenerates the Data and uses it to
C     check the accuracy of Reconstruction.
      EXTERNAL F
      DIMENSION W(800),IW(200),RESULT(11)
      COMMON TH(11),S(11)
      OPEN(UNIT=22,ACCESS='SEQIN',FILE='THETA')
      OPEN(UNIT=23,ACCFSS='SEQIN',FILE='OUTPUT')
      READ(22,*)( TH(I),I=1,11)
      READ(23,*)( S(I),I=1,11)
      A=0.0
      DO 10 I=1,11
      B=COSD(TH(I))
      EPSREL=0.01
      EPSABS=0.01
      CALL D01AJF(F,A,B,EPSABS,EPSREL,RESULT(I),
     1ABSERR,W,800,LW,200,IFAIL)
10    CONTINUE
      DO 29 I=1,11
29    RESULT(I)=2.0*RESULT(I)
      OPEN(UNIT=20,ACCESS='SEQOUT',FILE='BACDAT')
      WRITE(20,9)(RESULT(I),I=1,11)
9     FORMAT(11E11.5)
      STOP
      END
      FUNCTION F(X)
      COMMON TH(11),S(11)
      K=10*X
      J=K+1
      F=S(J)+(10.*X-K)*(S(J+1)-S(J))
      RETURN
      END
```

APPENDIX-E

Referring to the figure we can write,

$$d_{\theta,k} = 2\int_0^{R\cos\theta} (x^2+R^2\sin^2\theta)^k \, dx$$

$$= 2(x^2+R^2\sin^2\theta)^k \, x \Big|^{R\cos\theta} - k\int_0^{R\cos\theta} (x^2+r^2\sin^2\theta)^{k-1}(2x^2)dx$$

$$= 2\Big[R^{2k+1}\cos\theta - 2k\int_0^{R\cos\theta}(x^2+R^2\sin^2\theta)^k \, dx$$

$$+2kR^2\sin^2\theta \int_0^{R\cos\theta} (x^2+R^2\sin^2\theta)^{k-1} \, dx \Big]$$

$$d_{\theta,k} = 2R^{2k+1} \cos\theta - 2k \, d_{\theta,k} + 2kR^2\sin^2\theta \, d_{\theta,k-1}$$

$$= \frac{1}{2k+1}\Big[2R^{2k+1} \cos\theta + 2kR^2\sin^2\theta \, d_{\theta,k-1}$$

$$= \frac{2R^2\cos}{2k+1} \quad R^{2k-1} + k \sin \quad \tan \quad d \quad {}_{,k-1}$$

For ease in FORTRAN programming,

$$J_k^{(i)} = \frac{2R^2\cos\theta_I}{2k-1}\Big\{ R^{2k-3} + (k-1)\sin\theta_i \tan\theta_i \, J_{k-1}^{(i)} \Big\}$$

$$J_1^{(i)} = 2R \cos\theta_i$$

k= 2(1) - n

i= 1(1) - n

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